ANIMAL PARASITOLOGY

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ANIMAL PARASITOLOGY

WITH SPECIAL REFERENCE TO MAN AND DOMESTICATED ANIMALS

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PREFACE

This textbook has been prepared for the use of students in colleges, universities, medical schools, schools of hygiene and public health, schools of tropical medicine, and similar institutions. It is hoped that it will also be of use to veterinarians and practising physicians.

There is, at the present time, no textbook of parasitology in the English language that includes the many recent additions to our knowledge of this subject. Since the war, parasitology, especially those phases of the subject that concern the parasites of man, has practically been revolutionized. Many new species of parasites have been described and established and many others have been found to be of doubtful validity or identical with previously described species and hence have been dropped from the list. Much new information regarding the life-cycles of common parasites has been published within the past few years, and a more definite attack on the subject of host-parasite relations has been organized than ever before.

Because of space limitations it has been necessary to practise rigid selection with respect to the material included in this book. The parasites of man are emphasized throughout; those of domesticated animals are described wherever possible, since they are relatively easy to obtain for study and are of practical importance; and parasites of other lower animals are included because of their availability or their value for teaching purposes.

The book is divided into an Introduction and three Sections. The Introduction was prepared by the senior author, and the three Sections are the exclusive work of the author to whom they are credited, although each author has benefited by the advice of the others. The writers are indebted to their several colleagues for advice and criticism, especially to Dr. Justin Andrews, who read the Section on Protozoa, and Dr. W. W. Cort, who read the Introduction and the Section on Helminthology.

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INTRODUCTION

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INTRODUCTION

PARASITISM IN ANIMALS

Parasitology is the science or study of parasitism. Parasitism may be defined as the relation that exists between parasites and their hosts. A parasite is an organism that lives on, or within and at the expense of some other living organism. This book is limited in subject-matter to parasitism in animals. In the Introduction certain subjects are discussed that have a bearing on the phenomena of parasitism in general. In later chapters parasitism among the protozoa, worms and insects, is described and illustrated in detail.

I. *Animal Habitats*

The major habitats available on the earth for animals as usually recognized are (1) terrestrial, (2) fresh water and (3) marine. A fourth habitat should be added to this, namely, parasitic. Parasites have often been considered as living in the same habitats as their hosts but it is obvious that the environment of most of them is in reality radically different from that of the animals on or within which they live. For this reason it seems advisable to recognize a fourth major habitat with the characteristics common to those situations in which organisms live a parasitic existence. It is often assumed that parasites differ from free-living organisms in some more fundamental respect than habitat and very little attention is paid to this group of organisms in most textbooks and courses in zoölogy. As a matter of fact, as has been shown elsewhere (Hegner, 1926), the principles that govern the structure, life-cycles, habitats and activities of free-living and parasitic animals are really the same.

The activities of all animals may be separated into (1) those necessary for the maintenance of the individual and (2) those necessary for the maintenance of the race. The individual must be able to protect itself in its environment, to escape enemies, to reach a favorable situation in which to live, to find, capture, ingest, digest and assimilate food, to egest undigested material, to secrete pro-

tective substances, digestive juices and the like, to carry on respiration and to excrete waste products. Races are maintained by the asexual reproduction of the individuals of which they are composed, or by sexual reproduction or by both of these processes.

A comparison of any parasitic protozoön, worm or insect with nearly related free-living organisms will reveal the fact that both types of organisms are related in a similar way to their physical and biological environments. The relations between parasites and their hosts should, therefore, be studied as biological phenomena just as we are accustomed to study the relations between free-living organisms and their environment.

II. *Types of Association*

Living organisms, as just pointed out, must meet both physical and biological factors in their habitats. All living organisms are thus associated with other living organisms belonging both to the same species and to different species. Many types of association might be listed. Some of these are accidental or temporary, whereas others are invariable and permanent. Some of these types of association may be presented as follows:

(1) The two members of the association may be mutually and approximately equally benefited. For example, termites and their intestinal flagellates (p. 87).

(2) One member may secure an advantage from the association without the other undergoing any disadvantage. For example, *Trichodina pediculus* on *Hydra* (p. 171).

(3) One member may live more or less at the expense of the other without causing any injury to it. For example, bird lice (p. 597).

(4) One member may injure the body of the other but not enough to produce clinical symptoms unless present in large numbers. For example, hookworms in man (p. 387).

(5) One member may be distinctly pathogenic to the other, that is, may give rise to a diseased condition. The disease produced may be mild and only a contributory cause of death or may be severe and the direct cause of death. For example, *Endamœba histolytica* in man (p. 48).

III. *Types of Parasitism*

The term *parasitism* may be used in either a broad or a narrow sense. In a broad sense the word parasitism may be applied to any

association in which one species lives on or within the body of another species. In a more restricted sense parasitism involves an obvious injury by the parasite to the other member of the association, the host.

Symbiosis is a term that is frequently employed to describe a certain type of association between two species of organisms. This term was proposed by deBary in 1879 for the constant, intimate and mutually beneficial association of two organisms. Etymologically, symbiosis means simply "living together," and hence should include parasitism and other types of association. Usually, however, symbiosis is used to imply the permanent association of two specifically distinct organisms so dependent on each other that life apart is impossible.

Commensalism is another term in common use. It indicates an association in which one partner is benefited whereas the other is neither injured nor benefited; the former is the commensal and the latter the host.

Various types of parasites and hosts have been recognized by biologists. Some of these and certain terms commonly used by parasitologists are defined in the following list.

Commensalism. An association of two organisms one of which is benefited, the other being neither harmed nor benefited.

Host. An organism which harbors a parasite.

- Definitive host. The host which harbors the adult stage of the parasite.
- Intermediate host. The host which harbors the larval stages of the parasite.
- First intermediate host. The first host parasitized by the larval stages of the parasite.
- Second intermediate host. The host parasitized by the larval stages at a later period in the life-cycle.

Infection. The establishment of parasites within a host.

Infestation. A term sometimes used when the parasites do not multiply within the host.

Mutualism. An association of two organisms by which both are benefited.

Parasite. A plant or animal that lives upon or within another organism and feeds at its expense.

- Endoparasite. A parasite that lives within the body.
- Erratic parasite. A parasite that wanders into an organ in which it does not usually live.

Facultative parasite. An organism that is capable of living either free or as a parasite.

Incidental parasite. A parasite that establishes itself in a host in which it does not usually live.

Obligatory parasite. An organism that depends for its existence on its host.

Periodic parasite. A parasite that makes short visits to its host to obtain nourishment or other benefits.

Permanent parasite. A parasite that is parasitic throughout its entire life-cycle.

Temporary parasite. A parasite that is free-living during a part of its life-cycle.

Pathogenic parasite. An organism that may bring about harmful modifications that can be demonstrated in the living or dead host, but are not necessarily accompanied by symptoms.

Pseudoparasite. An object that is mistaken for a parasite.

Symbiosis. The living together of two organisms, two plants, two animals or a plant with an animal.

IV. *Effects of a Parasitic Existence on the Parasite*

The parasitic mode of existence has brought about modifications in structure and function and life-cycles among parasites that may be either characteristic of parasites in general or peculiar to particular groups, genera or species. These modifications may take the form of both simplification and complication. Frequently the terms degeneration or degradation are applied to changes that are brought about by a parasitic existence. Simplification and adaptation are better terms to use to describe the phenomena observed.

Changes in the organs of locomotion, nutrition and reproduction are rather general among parasitic organisms. For example, parasites are ordinarily transported from place to place by the host and frequently are transmitted from one host to another without any effort on their part. It is, therefore, not strange that the locomotor organs of parasites should become simplified or should be in some cases absent entirely. Organs of nutrition are also often modified or lost, since the normal condition for parasites is life in an organic medium from which food is absorbed through the surface of the body. The reproductive organs of parasites, on the other hand, are frequently larger and more complicated than those of free-living relatives, and the number of eggs produced by parasites is in general many times

as great as that of nearly related free-living species. This must necessarily be so, because the chances of an egg of a parasite producing an offspring which will succeed in establishing itself within another host are very slender indeed.

The structural or physiological modifications of parasites may be characteristic of groups, genera or species, as stated above. Modifications of this type will be noted in the descriptions of the various species dealt with in later chapters of this book.

V. *Parasitism in the Animal Kingdom*

Almost every large group in the animal kingdom contains parasitic species. There are very few of these, however, in certain phyla and large numbers in other phyla. A survey of the animal kingdom shows clearly that the parasites of principal importance are included in the phylum PROTOZOA, several phyla of worms and the phylum ARTHROPODA. The following list presents in abbreviated form the phyla of the animal kingdom and the groups that contain parasitic species.

Phylum I. PROTOZOA. Unicellular animals.

- Class 1. SARCODINA. Free-living and parasitic. Parasitic amœbæ in man and lower animals.
- Class 2. MASTIGOPHORA. Free-living and parasitic. Intestinal and blood-inhabiting parasites of man and lower animals.
- Class 3. SPOROZOA. Parasitic. Coccidia and malaria parasites in man; parasites in intestine, blood and tissues of lower animals.
- Class 4. INFUSORIA. Free-living and parasitic. *Balantidium coli* in man; various species in lower animals.

Phylum II. PORIFERA. Sponges. Very few parasites.

Phylum III. CŒLENTERATA. Polyps, jellyfishes, sea-anemones and corals. Very few parasites.

Phylum IV. PLATYHELMINTHES. Flatworms. Free-living and parasitic.

- Class 1. TURBELLARIA. Mostly free-living; e.g., *Planaria.*
- Class 2. TREMATODA. Parasitic. Flukes.
- Class 3. CESTODA. Parasitic. Tapeworms.

Phylum V. NEMATHELMINTHES. Round worms. Free-living and parasitic in man and lower animals; e.g., hookworms, ascarids and trichinas.

Groups of Uncertain Systematic Position.

1. ACANTHOCEPHALA. Spineheaded worms. Parasitic in man and lower animals.
2. GORDIACEA. Hair worms. Parasitic in insects.

Phylum VI. ECHINODERMATA. Starfishes, sea-urchins. Free-living.

Phylum VII. ANNELIDA. Segmented worms. Free-living and parasitic; e.g., earthworms (free-living) and leeches (parasitic).

Phylum VIII. MOLLUSCA. Snails, clams, squids. Mostly free-living.

Phylum IX. ARTHROPODA. Crayfishes, insects, spiders, centipedes. Free-living and parasitic; many species act as intermediate hosts of parasitic PROTOZOA and worms.

Class 1. CRUSTACEA. Crayfishes, etc.; many parasites of fish.
Class 2. MYRIAPODA. Centipedes.
Class 3. INSECTA. Insects. Many parasitic and many intermediate hosts.
Class 4. ARACHNIDA. Spiders, scorpions, mites, ticks. Many parasitic.

Phylum X. VERTEBRATA. Fish, amphibians, reptiles, birds, mammals. Mostly free-living, but each group contains species that may be classed as parasites in a broad sense.

VI. *Host-Parasite Specificity*

By host-parasite specificity is meant the character of the association of a particular species of host with a particular species of parasite. This subject involves especially the facts and nature of host susceptibility and parasite infectivity.

1. HOST SUSCEPTIBILITY

Parasitologists have long recognized different types of hosts with respect to their susceptibility to various parasites. Thus if a host is easily parasitized by a certain species it is said to be tolerant, whereas if it is difficult to parasitize it is classed as refractory. A host that is frequently found parasitized by a certain species in nature is known as a natural host; whereas one that does not become so parasitized may be considered a foreign host. If a species of para-

site that habitually lives in or on a certain host species is found in or on a host that is very seldom infected that host is spoken of as an accidental or casual host. A host may become infected but throw off the infection after a short time, in which case it is known as a provisional or transitory host; or it may serve as a host for a short stage in the life-cycle of a parasite, thus becoming a temporary host.

Frequently it is possible to infect species of hosts in the laboratory that do not become infected, as a rule, in nature, either because their habits are such that they do not come into proper relations with the parasites or because they are refractory except when large numbers of parasites are present or when these are administered to them in certain definite ways not usually possible in nature.

Whether or not a susceptible species of animal becomes infected with a particular species of parasite in nature depends primarily on three factors: (1) animal and parasite must live in the same geographical region, (2) the habits of the animal must be such as to bring it into proper relations with the infective stage of the parasite and (3) the life-cycle of the parasite must be such that its infective stage is reached when and where the host is available to be parasitized.

The first factor mentioned is so obvious that little discussion is necessary. The absence of certain diseases from certain regions is frequently due not to the absence of susceptible hosts but to the absence of the parasites. This, for example, may account for the absence of malaria from countries where susceptible human hosts and the proper species of anopheline mosquitoes exist but where the malarial parasites have never been introduced. On the other hand, many cases might be cited of diseases that have appeared in various regions previously free from them because of the introduction of the causative parasite.

The other two factors are really the same considered from the two standpoints of host and parasite respectively. If the life-cycle of a parasite and the activities of its natural host are studied side by side it will appear as though both host and parasite were actually trying to bring about a situation favorable for infection. For example, the gametocytes of the malarial organisms live in the peripheral blood where they cannot fail to reach the stomach of the mosquito that sucks up the blood; the infective sporozoites congregate in the salivary glands of the mosquito where they seem to lie in wait to be inoculated into a new host. The mosquito feeds on the blood of man and thus enables the parasites to enter the blood stream; whereas it might feed on fruit juices as it is able to do in the lab-

oratory. The infective mosquito bites usually at night when the host is asleep and is thus able to inoculate the sporozoites successfully during an uninterrupted meal. A change in any one of these conditions might easily bring about the annihilation of the race of parasites; for example, if the gametocytes were localized in the internal organs of man or if the sporozoites did not reach the salivary glands of the mosquito there would be no spread of malaria and the disease would soon die out.

An infection that involves injury to the host may be acute, malignant, fulminating, chronic or benign, but the evidence does not indicate that the susceptibility of the host to an infection has any bearing on the character of the infection induced. That is to say, a host may be more susceptible to infection, and probably usually is, by a species of parasite that never calls forth symptoms than by a pathogenic or lethal species.

2. PARASITE INFECTIVITY

If a host is easily parasitized by a species, the parasite is said to be highly infective. How much its infectivity is due to the host and how much to the parasite it is impossible to say. Several of the terms noted above with respect to hosts are also commonly used to designate different types of parasites. Thus, we speak of natural parasites, accidental parasites, and provisional, transitory or temporary parasites. Parasites are also classified according to the necessity of existence within a certain host, as facultative, when this is not required, and obligate, when the parasite is unable to live in any other host. The invasive powers of a parasite are indicated by such terms as virulent or aggressive, and the degree of infectivity with respect to the effects on the host as pathogenic, sublethal and lethal.

That the hosts differ in susceptibility to a given parasite has been abundantly demonstrated. The differences may be racial, familial or individual, i.e., susceptibility may be inherited. It would be interesting to study this subject with hybrids between susceptible and non-susceptible hosts. Sex and age may also have a profound effect on host-parasite specificity. In general young animals are more susceptible to infection than adults.

The physiological state of the host may have an important bearing on its susceptibility. Frequently a refractory host may become infected if his resistance is lowered by overwork, by previous infection with other parasites, by malnutrition, intoxication, by exposure to

wet and cold, by trauma or by shock. Changes in physiological state no doubt also take place in parasites which raise or lower their powers of infectivity. Other factors that cause no inconvenience to the host may be unfavorable for the parasite.

The origin of host-parasite specificity is really synonymous with the evolution of parasitism. It is obvious that parasitism cannot exist unless the hosts and parasites involved are present in the same region and behave in such a way as to come frequently into contact. If these conditions are fulfilled, the factors that make it possible for the parasite to live and reproduce within the host present themselves for consideration. Thus it seems certain that man often takes in with his food the infective stages of many parasites of lower animals. These organisms are not able to remain in the body of man because man does not tolerate them.

But what factors are responsible for tolerance or refractoriness and how have these conditions arisen in the course of evolution? Some of the factors involved have been discussed above, and, as we have seen, are still very obscure. We must base our studies on the conditions of host and parasite as we find them to-day without much consideration of how the present status has been reached. There can be little doubt, however, but that long association has brought about changes in both host and parasite which make it possible for them to live together in harmony except under special conditions. An increase in the virulence of the parasites might disturb the equilibrium established and bring about pathological conditions in the host; a decrease in the resistance of the host might have the same effect; or a decrease in the aggressivity of the parasite might prevent infection; and an increase in the resistance of the host might also prevent infection.

3. PROBLEMS IN HOST-PARASITE SPECIFICITY

The subject of host-parasite specificity offers many problems for investigation. Material for study can be obtained easily and results promise to be of great importance to the subject of host-parasite relations. Some of these problems may be stated as follows:

(1) To what extent does the behavior of the host and that of the parasite determine host-parasite specificity?

(2) Do species of parasites that are restricted to one species of host gain access to other species of hosts?

(3) What factors within a host enable natural parasites to bring about an infection and prevent foreign parasites from doing so?

(4) How may we account for laboratory infections in foreign hosts?

(5) What conditions are responsible for differences in susceptibility between young and adult animals?

(6) What host-parasite interactions terminate an infection or bring about periods of latency and relapse?

VII. *Host-Parasite Relations*

In general, the series of events that constitute the relations of host and parasite may be considered as beginning with the transmission of the parasite from one host to another. Then follow the distribution and localization of the parasite on or within the host, the growth or multiplication of the parasite, the resistance of the host to the parasite and of the parasite to the host, the method of attack of the parasite, changes in the host brought about by the parasite and those in the parasite due to residence in the host, host-parasite adjustments during the infection, the escape of infective stages of the parasite from the host and the recovery or death of the host. These will now be considered in order for parasites in general and a similar method of presentation will be used in the case of specific parasites in later chapters with modifications necessitated by the peculiarities characteristic of each species.

I. EPIDEMIOLOGY OF TRANSMISSION

Infective stage. The stage in the life-cycle of a parasite that escapes from the body of the host is either infective to fresh hosts or develops to the infective stage outside of the body. During this period the parasites are usually subjected to external environmental factors and most of the parasites perish, but as long as a race continues it is obvious that a certain number survive and set up infections in fresh hosts. At one time it was supposed that disease-producing organisms might multiply outside of the body of the host and bring about foci of infection in soil or water, but we now know that in most cases there is no reproduction of the parasite during its life in the outer world. (See *Strongyloides stercoralis*, p. 376).

Avenues of infection. Reaching and invading a new host is certainly one of the most serious problems in the entire life-cycle of a parasite and only the smallest proportion of the total number of infective organisms reach a susceptible animal in or on which

to live. Only the almost inconceivable fecundity of the parasites prevents the various species from dying out.

Transmission by contamination is a very effective method for a parasite to reach a new host. The organism while outside of the body may reach the food or drink of man by contamination because of unsanitary conditions due to neglect on the part of the host or through the agency of flies and other animals. Many parasites are protected by resistant walls in the cyst or egg stage which keep them viable until they are ingested by a new host.

Another method of transmission is by "contagion" or direct transference from one host to another. Thus parasites that live in the human mouth may be transferred from one person to another by kissing.

A third method of transmission is that by inoculation through the agency of an intermediate host. The mosquito, as we shall find later, is one of the most efficient vectors of parasites since mosquitoes are the transmitting agents of the organisms of malaria, filariasis and other parasites.

The so-called "hereditary" method of transmission is not known to occur in any parasites that live in man, but certain species that parasitize lower animals make their way into the eggs of these animals and hence parasitize the new generations that develop from these eggs.

Prenatal transmission occurs rather frequently, especially in the case of parasitic worms, and certain of the latter may actively penetrate the skin of the host or gain entrance to the definitive host when insufficiently cooked meat from parasitized intermediate hosts is eaten.

One interesting fact that is made clear by the study of the epidemiology of transmission is that in most cases the parasite is passive during its transfer from one host to another and transmission is almost entirely due to the activity of the host or of intermediate hosts. Simple sanitary measures, such as the prevention of soil pollution and protection against mosquitoes, are usually all that are necessary to protect human hosts from infection with such organisms as intestinal protozoa and worms and the parasites of malaria and filariasis.

2. CLINICAL AND PARASITOLOGICAL PERIODS DURING THE COURSE OF A NATURAL INFECTION

The relations of host and parasite during what may be called a natural infection, as distinguished from the invasion of a host by

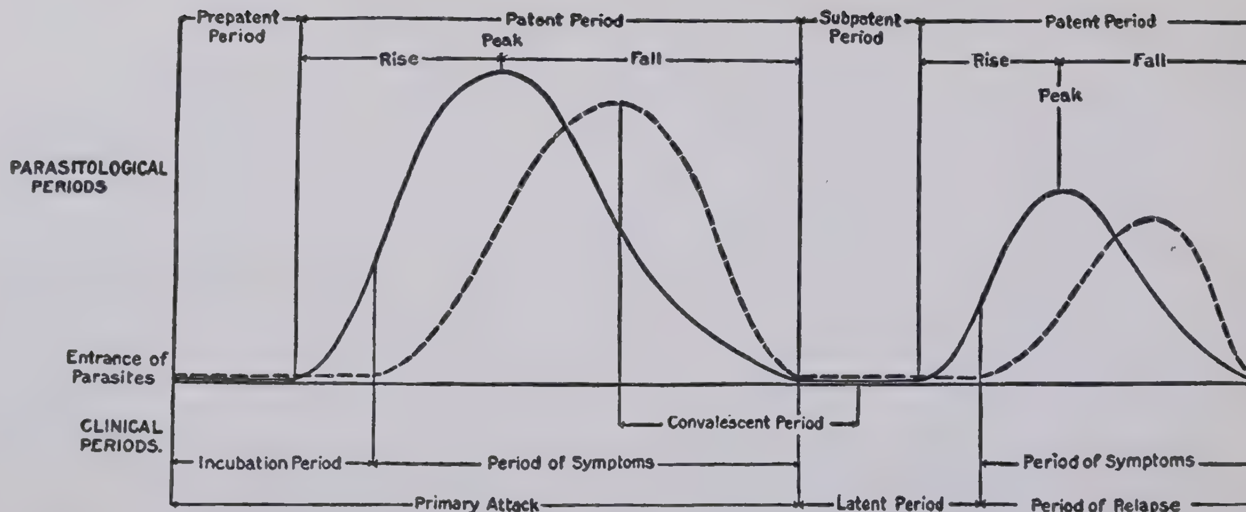


Fig. 1.—Parasitological and clinical periods, especially in protozoan infections. This illustration is intended to represent by means of curves the parasitological and clinical periods in the course of infections, especially with pathogenic protozoa. It represents in a general diagrammatic way the course of natural infections, consisting of a primary attack followed by apparent recovery of the host. This completes both the parasitological and clinical manifestations of disease in cases such as oriental sore in which one attack gives immunity. In other diseases, however, such as amœbic dysentery and malaria, the primary attack is often followed by a symptomless period when the parasites are latent. Eventually the parasite number again increases, symptoms reappear and the host is said to suffer a relapse. The terms used are fully described in the text. (From Hegner)

foreign parasites or infections complicated in various ways, may be divided into two types of periods—periods that refer to the reactions of the parasite in the host and periods descriptive of the reactions of the host to the parasite. These periods are presented in diagrammatic form in Figure 1. They may be defined briefly as follows:

The *Prepatent Period* extends from the time the infective parasites enter the body of the host until their eggs, cysts or other stages in their life-cycle can be recovered by specified laboratory methods. The length of this period obviously depends to some extent on the character of the laboratory technique employed.

The *Patent Period* covers the interval during which the parasites can be demonstrated by the technique employed. In the PROTOZOA the parasite number undergoes a rise during this period, reaches a peak, and then suffers a fall. The patent period ends when the parasites can no longer be recovered. In worms the patent period lasts as long as the parasite continues to lay eggs.

In many protozoan infections the patent period is followed by a *Subpatent Period* of indefinite length. During this period parasites cannot be recovered by the usual laboratory methods but their presence can be proved in various ways depending on the species of parasite.

The subpatent period may be followed by a second patent period during which the parasite number rises, reaches a peak, and falls, but often does not rise as high as in the primary attack.

The *Incubation Period* extends from the time of entrance of the parasites until symptoms appear. This period is usually longer than the prepatent period, but may be shorter.

The *Period of Symptoms* begins when the incubation period ends and ends of course with the cessation of symptoms. In helminth diseases the symptoms induced are chronic.

The *Convalescent Period* is represented in protozoan diseases as beginning at the point of maximum symptoms and ending with the recovery of the host.

In diseases characterized by relapses one or more *Latent Periods* may be present. During these periods the causative organisms are too few in number to bring about symptoms, but, after intervals of indefinite length, some change occurs in parasite, or host or in both that results in an increase in parasite number and a reappearance of symptoms.

The reappearance of symptoms following a latent period is known as the *Period of Relapse.*

The curves as given probably do not represent actual conditions

in any specific protozoan infection but are meant to indicate that in general the increase in parasite number precedes the appearance of symptoms and that increases and decreases in the severity of the symptoms follow the rise and fall in parasite number.

3. DISTRIBUTION AND LOCALIZATION OF PARASITES ON OR WITHIN THE HOST

Different species of parasites become localized on different parts of the body or in different organs, tissues or cells. Thus parasites may be localized in cavities, such as the lumen of the intestine, or in tissue, for example, muscle parasites, or be intracellular as is true of the malaria parasite which lives inside of the red blood cells. We know something about the factors that bring about the distribution of parasites on or within the body of the host but there is much still to be learned about this subject.

The attack of the parasite usually takes place at the point of localization. This becomes the primary site of infection. In many cases a parasite does not remain in or on a particular part of the body but spreads to other parts where it begins attacks at what are called secondary sites of infection. It may be said in general that distribution is due primarily to the physiological activities of the host and localization, to host-parasite interactions, the parasites setting up an infection wherever favorable conditions exist.

4. THE PASSIVE RESISTANCE OF HOST AND PARASITE

The host characteristics that prevent the establishment of a parasite may be referred to as passive resistance. Each type of parasite encounters various obstacles that must be overcome before a host can be successfully invaded. Some of the factors that prevent infection are easily determined whereas others are still problematical.

The invading parasite must be able to resist conditions in the host that may be unfavorable. A parasite, for example, that sets up an infection in the large intestine may have to pass through the preceding sections of the digestive tract. In many cases the organism is surrounded by a protective wall which successfully resists adverse conditions in the mouth, stomach and small intestine. Blood-inhabiting parasites that are transmitted by intermediate hosts, such as the mosquito, do not need to be protected by resistant walls since they are inoculated directly into the blood stream. In the blood stream, however, they must be able to withstand the serum and escape phagocytosis.

5. THE PARASITE'S METHOD OF ATTACK

Having reached the primary site of infection the true infection of the host begins. Each parasite has its own particular method of attack and the different types of parasitism are distinguished largely on this basis. In most cases of parasitism the parasite is able to live and reproduce for many years within the host without apparent injury to it. It is obvious that the degree of injury depends on which organs or tissues are invaded and on the degree and rapidity of tissue destruction or on the production of toxic substances. Slight injuries inflicted slowly are usually repaired by the host as they occur, whereas serious injuries that are quickly produced lead to symptoms. If the host develops severe symptoms both it and the parasites are in danger and if the host dies the parasites usually die with it. This type of parasitic attack is unusual and is considered to represent a comparatively recent association since most parasites live in harmony with their hosts—a condition that is supposed to have developed during the course of evolution.

6. CHANGES IN THE HOST CAUSED BY THE PARASITE

Parasites that injure their hosts are pathogenic. If the injuries are so severe as to interfere radically with the normal functions of the organs of the host, symptoms appear. The host may build up an active resistance against such an attack, which we call immunity. The pathology of most parasitic diseases is well known, but very little is known about the genesis of the conditions observed. Likewise, the symptomatology of the parasitic diseases of man has been thoroughly described, but the way in which the functions of the organs are disturbed is still obscure. There is no doubt that the human host builds up an immunity against certain parasites. This subject, however, is one that has been very little studied.

7. CHANGES IN THE PARASITE DUE TO RESIDENCE IN THE HOST

Since parasites are living organisms, they also are probably capable of building up active resistance against the attacks of the host. It is obviously difficult to demonstrate such a parasite immunity, although "fastness" among the PROTOZOA may be due to such a phenomenon. Whether changes in virulence may occur in a strain of parasites while residing in a host is still an open question.

8. HOST-PARASITE ADJUSTMENTS DURING AN INFECTION

Carriers. The continued increase in numbers of parasites, due to reproduction or reinfestation without check, would obviously result in the death of the host. As stated above, parasites do not destroy their hosts in most cases. Frequently in protozoan infections, the host, by means of acquired resistance, is able to destroy most but not all of the parasites and hence to bring about what is known as the carrier condition. Such a carrier is a host in which parasites live and by which they are disseminated but which exhibits no visible symptoms of infection. Carriers may be divided into two types, contact carriers, who are parasitized but have never exhibited symptoms, and convalescent carriers, who have recovered from a parasitic disease but are still infected. Certain species of hosts are almost universally infected in nature by certain species of parasites and a parasitized condition might almost be considered the normal state of such a species. Carriers are frequently spoken of as reservoirs since they are storehouses for the organisms that are responsible for the spread of the parasite to new hosts. Certain parasites are infective both to man and to lower animals and one or both kinds of hosts may serve as reservoirs.

Latency. Parasites are said to be latent when they are present in a host but do not make themselves manifest. The infected host may show no symptoms or may have recovered from symptoms and still harbor parasites. In either case, the condition is known as latency. Certain changes in host or parasite may bring on symptoms in a host that had never previously exhibited evidence of infection. Such a case might be considered only an extended incubation period.

Relapse. When a host that had previously shown symptoms but had apparently recovered again exhibits symptoms following a period of latency, the condition is known as a relapse. Relapses are of frequent occurrence in many parasitic diseases. They must be due to some change in the relation between the host and parasite but just what changes are responsible for the increase in the number of parasites and the reappearance of symptoms is known in very few cases.

9. ESCAPE OF PARASITES FROM THE HOST

Parasites obviously must escape from the host in which they are produced in order to bring about the infection of new hosts and thus prevent the race from dying out. The different types of parasites follow different routes in escaping from their hosts. Many of

them attack parts of the host from which natural channels lead to the outside; for example, intestinal parasites pass out with the feces. Other species are extracted from a host by blood-sucking vectors. The method of escape of each type of parasite considered in this book will be described in an appropriate place in later chapters.

VIII. *Origin and Evolution of Parasitism*

We really know nothing definite about the origin and evolution of parasitism, since no one has ever observed a free-living species become parasitic, but there are many known facts that are of value in any attempt to work out lines of descent.

(1) In the first place, the parasitic habit must be more recently evolved than the free-living habit, since free-living forms must have existed before the parasites could obtain hosts on which to live.

(2) Ectoparasites probably evolved before endoparasites, because the change from a free-living existence to that of ectoparasitism does not appear to be so difficult as to that of endoparasitism.

(3) Inasmuch as there are free-living as well as parasitic species in many large groups of animals, it is evident that the parasitic habit has arisen independently in each of these groups and may therefore be considered of rather common occurrence during the course of evolution.

(4) Most parasites belong to groups that are more primitive than their hosts, i.e., are lower in the scale of life. PROTOZOA cannot be parasitized by animals more primitive than themselves, but may be parasitized by plant organisms.

(5) Certain ectoparasites are not limited to one species of host; others have been observed on only one species; and certain ectoparasites are confined to a definite part of the body of the host. These are supposed to be stages in the evolution of ectoparasitism. A species that is able to migrate from one species of host to another is probably in a more primitive stage of parasitism than one that is limited to one host, and the latter condition has probably originated from the former. The third type of ectoparasite mentioned represents a still further specialization, the parasite being limited to a single organ of the host.

(6) The relations between ectoparasitism and endoparasitism, and commensalism and symbiosis furnish much material for speculation. Do commensalism and symbiosis lead to parasitism? Many students believe that they do. For example, a species that takes its meals in a state of mutualism with another species might develop

into a food robber and from this into an actual parasite; or, symbiotic relations might become disturbed and instead of a more or less mutual association one member might develop gradually into a pathogenic parasite.

(7) Endoparasites may be limited to one species of host or may pass through part of their life-cycle in one host and part in another. How did endoparasitism arise and which of the two conditions mentioned is the more primitive? Endoparasitism may have arisen from ectoparasitism, from commensalism or from symbiosis. If an endoparasite is restricted to one species of host it probably adopted the parasitic habit within this species and is therefore no older phylogenetically than its host. Any changes that have taken place in the parasite have probably proceeded coincident with changes in its host. When an endoparasite occurs in several species of hosts, the parasite is probably older than its hosts, having adapted itself to hosts that evolved after it became a parasite.

(8) Parasites that have intermediate hosts have probably evolved from parasites with only one species of host. This condition may have arisen because of the ability of the parasite to adapt itself to changed conditions, at first simply tolerating the second host but later actually establishing itself within it. The entrance of exogenous stages of parasites into other animals is very widespread in nature, and plenty of opportunity exists for parasitism to arise.

IX. *Parasitism and the Geographical Distribution and Evolution of Hosts*

One of the most interesting phases of parasitism is that involving its bearing on the geographical distribution and genetic relationships of hosts. Von Jhering in 1902 was among the first to discuss this problem in cases of parasitic worms. He argues that two species of hosts are of common descent if they are parasitized by the same species or nearly related species of parasites. He believes that the close relationship of the parasites indicates that they come from a common ancestor and that the different species of hosts involved descended from an ancestral host that was infected by the ancestral parasite. Similar arguments were employed by Zschokke (1904) to account for the distribution of certain cestodes in marsupial mammals.

How the migration of salmon may be inferred from the character of its helminthic parasites is also pointed out by Zschokke (1903).

The original home of the salmon is not necessarily indicated by the present path of its migration nor by the locality of its breeding ground, but the fact that a large proportion of its endoparasites are those of marine animals seems to prove that the ancestral home of this type of fish was the sea and not its present breeding ground, which is in fresh water. "Each parasitic fauna," says Zschokke, "comes to be to some extent a mirror image of the biology of the host, of its habits of life and especially of its relations to those creatures that share the habitat with it. Each change of nourishment and residence of an animal finds its echo in the changes in the helminthic condition."

The best work of this type on PROTOZOA is that done by Metcalf (1923). Metcalf discusses, for example, the distribution of the family LEPTODACTYLIDÆ. These are "frogs" characteristic of two widely separated geographical regions, (1) tropical and semi-tropical America and (2) Australia and Tasmania; they have been reported from no other parts of the world. There are two hypotheses that may account for this discontinuous distribution: (1) there may have been a former connection between Patagonia and Australia by way of Antarctica over which these frogs were continuously distributed, or (2) resemblances of the frogs of America and Australia may be due to convergent or parallel evolution.

Frogs of the family LEPTODACTYLIDÆ contain, in the rectum, opalinid parasites of the genus *Zelleriella*. These parasitic ciliates are present in the frogs of this family living in both America and Australia. They are so nearly alike in the frogs of the two regions that they can be separated specifically only with difficulty. It is possible that either the frogs or the opalinid ciliates may have arisen by convergent or parallel evolution. It seems very improbable, however, that both the frogs and opalinids arose in this way. The conclusion is reached that the first hypothesis is correct and that a former land connection existed between Patagonia and Australia by means of which frogs of this family, together with their opalinid parasites, migrated to Australia.

Practically all parasites lend themselves to studies of this type. Kellogg (1905) has used the method in his work on bird lice; Johnston (1914) has studied problems of evolution and zoögeography by the use of trematodes and cestodes and Darling (1920) has studied the migrations of human races from data of hookworm distribution. In this way parasitology has proven itself a valuable aid in the study of geographical distribution and evolution.

X. *Rules of Nomenclature*

The correct scientific name of many parasites is at present in doubt. This is due in part to the failure of certain investigators to follow the rules of nomenclature in describing new species and in part to the tendency in many cases to name new genera and species without sufficient study of the organism or of the group to which it belongs. In 1898 the International Congress of Zoölogy organized an International Commission on Zoölogical Nomenclature which has served since that time and has prepared a set of International Rules of Zoölogical Nomenclature. These rules apply to family, subfamily, generic, subgeneric, specific and subspecific names. They cover the formation, derivation, and orthography of zoölogical names, the author's name, the law of priority and its application and the rejection of names. According to these rules, zoölogical and botanical names are independent, hence the same genus and species name may be applied to both an animal and a plant, although this is not recommended; scientific names must be Latin or Latinized; family names are formed by adding *-idæ* to the stem of the name of the type genus; generic names should consist of a single word, written with a capital initial letter and italicized; specific names are adjectives agreeing grammatically with the generic name, substantives in the nominative in apposition with the generic name, or substantives in the genitive, and should be italicized; the author of a scientific name is the person who first publishes the name with a definition or description of the organism given. If a new genus is proposed, the type species of the genus should be designated. Type species should be deposited some place where they are accessible and a statement regarding their location included in the publication in which they are described. The list of International Rules of Zoölogical Nomenclature was published in pamphlet form in the *Proceedings of the Biological Society of Washington,* vol. xxxix, 1926, pp. 75-104, and also in Wenyon's *Protozoölogy,* vol. ii, 1926, pp. 1336-1349. These are complete except for an amendment published in *Science,* vol. lxvi, 1928, pp. 17-18.

Section I

PROTOZOÖLOGY

BY

ROBERT HEGNER

CHAPTER I

THE BIOLOGY OF THE PROTOZOA

As noted in the Introduction, a large number of parasitic animals belong to the Phylum PROTOZOA. In this section attention will be directed primarily to this type of PROTOZOA. However, most of what we know regarding the morphology, physiology and reproduction of the PROTOZOA has been learned by the study of free-living species. To understand the nature and activities of parasitic species it is, therefore, necessary to know something about the biology of the entire group. For this reason Section I on PROTOZOÖLOGY is introduced by this chapter on the Biology of the Protozoa.

The study of the biology of the PROTOZOA involves first of all a knowledge of these organisms sufficient to enable one to recognize the class, order, genus and species to which the various members of the Phylum belong. To gain this knowledge one must study the morphology and classification of PROTOZOA in general. This having been done one may then proceed to inquire in what types of habitats PROTOZOA live, how they maintain themselves in their various habitats and how races of PROTOZOA are maintained.

I. *Morphology*

PROTOZOA are usually designated unicellular animals to distinguish them from the METAZOA which are many-celled animals. Most PROTOZOA possess in fact the characteristics of a single cell. The body consists of protoplasm which is of two principal types, cytoplasm and nucleoplasm, but there are almost countless variations in the shape and size of the body and in details of structure. As regards size, PROTOZOA are all small as compared with METAZOA, most of them being invisible to the naked eye. They can, therefore, be studied successfully only with the help of a microscope. Each species of protozoön has a characteristic shape, a feature which is of particular value in the identification of species. Even amœbæ, which have been defined as shapeless masses of protoplasm, can usually be separated into genera and species on the basis of body shape.

The cytoplasm of the protozoan body is usually divisible into two parts, a clear thin layer of ectoplasm at the surface and a more fluid, granular inner portion, the endoplasm. The ectoplasm at the periphery is in contact with the environment of the organism and it is, therefore, not strange that locomotor organs, skeletal and supporting structures and organs of attachment should be formed of this substance. In the endoplasm are various inclusions, the most important of which are nuclei, food vacuoles, contractile vacuoles, plastids and various other bodies concerned in reproduction and other vital activities.

The organs of locomotion of PROTOZOA are of particular interest because of their functions both of locomotion and food capture and their use in separating the PROTOZOA into classes. It is customary to characterize the classes of PROTOZOA on the basis of the presence or absence of locomotor organs and the nature of these when present. Pseudopodia are characteristic of the Class SARCODINA, flagella of the Class MASTIGOPHORA, cilia of the Class INFUSORIA and the fourth Class, the SPOROZOA, is characterized by the absence of organs of locomotion. Different species of amœbæ differ with respect to the shape and size of their pseudopodia and the method of their formation. Flagella are fine thread-like organelles that consist, in at least some cases, of two parts, a central axial filament capable of vibration, and a surrounding elastic sheath. The diameter, length and number of flagella are constant for each species of mastigophoron and hence of considerable value in identifying species. Cilia are really small flagella, being usually shorter and thinner but structurally similar. They are ordinarily more numerous, and definitely arranged on the surface of the body according to the species. Cilia may become fused together in the oral region to form membranelles or into spine-like structures known as cirri. Cirri are especially characteristic of hypotrichous ciliates, where they occur on the ventral surface and are used much like legs in walking or running.

In many PROTOZOA there is a definite region of the ectoplasm known as the peristome in which there is a funnel-shaped depression or tube, the cytopharynx, the opening of which is known as the cytostome or mouth. Such a structure is characteristic of many of the INFUSORIA and serves to transport food into the endoplasm. At the so-called posterior end of the body there may be a less complex opening in the ectoplasm, the cytopyge, through which ingested particles are cast out.

Skeletal and supporting structures are present in many species of PROTOZOA. These are formed by the protoplasm of the organism or

by the acquisition of minute foreign bodies such as sand crystals or diatoms. The common fresh water genus *Arcella* possesses an external shell formed by the organism, whereas its near relative, *Difflugia,* builds its external skeleton of minute sand grains. Some of the SARCODINA, especially the HELIOZOA, RADIOLARIA and FORAMINFERA construct elaborate internal skeletons of silica or calcium carbonate. Skeletal and supporting structures other than peripheral membranes and cyst walls are not common among parasitic PROTOZOA.

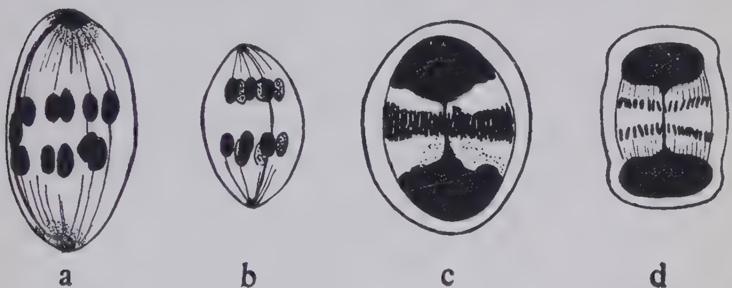


FIG. 2.—Nuclei of various species of SARCODINA in mitosis (x 4000). (From Kofoid and Swezy)

a. *Endamœba coli.* (After Swezy)
b. *Endamœba histolytica.* (After Kofoid and Swezy)
c. *Amœba diplogena.* (After Bělař)
d. *Vahlkampfia diplomitotica.* (After Aragão)

Most of the PROTOZOA possess a single nucleus. The INFUSORIA, however, are characterized by the presence of two nuclei of different sizes, a large macronucleus and a smaller micronucleus. Certain members of each of the four classes of PROTOZOA are provided with more than one nucleus; in some the number may reach into the hundreds. Besides the nucleus several types of vacuoles may occur in the endoplasm: more or less permanent vacuoles filled with fluid, food vacuoles containing ingested solid particles and contractile vacuoles which periodically expel excretory products to the outside through the ectoplasm. Plastids of various types may also occur in the bodies of PROTOZOA. The location, morphology and functions of these will be discussed in later chapters. Examination of the morphology of the PROTOZOA very quickly convinces one that these animals are not the simple organisms that they are usually represented to be. They are frequently said to resemble a cell, being "a mass of protoplasm containing a nucleus." The illustration of *Diplodinium ecaudatum* on page 175 indicates how really complicated the body of a protozoön may be.

II. *Classification*

In a book on Parasitology no detailed classification of the Phylum PROTOZOA is necessary since, although the species considered are described according to the class in which they belong, only the larger taxonomic divisions need be recognized. The four classes with examples of common species are as follows:

Class 1. SARCODINA. PROTOZOA with pseudopodia; usually without a cuticular cell wall; often with a shell or skeleton. Free-living examples: *Amœba proteus, Arcella vulgaris, Actinophrys sol, Polystomella crispa.* Parasitic examples: *Endamœba histolytica, Endolimax nana, Iodamœba williamsi.*

Class 2. MASTIGOPHORA. PROTOZOA with flagella; many colonial. Free-living examples: *Euglena viridis, Mastigamœba invertens, Chilomonas paramœcium, Synura uvella.* Parasitic examples: *Trichomonas hominis, Trichonympha campanula, Trypanosoma gambiense.*

Class 3. SPOROZOA. PROTOZOA without locomotor organs; spore production a characteristic of the life-cycle. Examples: *Monocystis agilis, Isospora hominis, Hæmogregarina muris, Plasmodium vivax.*

Class 4. INFUSORIA. PROTOZOA with cilia; usually with two nuclei, a macronucleus and a micronucleus. Free-living examples: *Paramœcium caudatum, Spirostomum ambiguum, Euplotes patella, Podophrya collini.* Parasitic examples: *Opalina ranarum, Balantidium coli, Nyctotherus ovale, Trichodina pediculus.*

III. *Maintenance of the Individual*

PROTOZOA in their active stages live in a fluid medium. This may be fresh water, salt water or the body fluids of other organisms, either plants or animals. Here they are subjected to various physical and biological factors such as changes in temperature, changes in the chemical composition of the medium, movements of the medium and the like. Only a small proportion of the individuals succeed in their struggle with their environment, but a sufficient number grow to maturity and produce offspring to perpetuate the race. The principal activities necessary for the maintenance of the individual protozoön are discussed in the following paragraphs.

I. PROTECTION

PROTOZOA must protect themselves from competitors, animals and physical agents. Many of their devices are similar to those of higher animals. Some of them resemble their surroundings in shape and color and hence escape detection. They may be protected from physical agents by a firm cuticle, resistant wall or external skeleton. With the air of their pseudopodia, flagella or cilia they are able to move out of an unfavorable location into a satisfactory environment. Some PROTOZOA possess weapons of defense or offense such as the trichocysts of *Paramœcium.* Secretions and excretions that are repellent in nature serve as a protection for certain species, and finally, if molar agents in the medium bring about mechanical injury, the powers of regeneration of the organism frequently are such as to bring about a reformation of the complete animal.

2. RESPONSE TO STIMULI

Because of that fundamental property of protoplasm, irritability, PROTOZOA respond to various stimuli. Some of these are external and others originate within the body of the animal. Due to these responses to stimuli, which, taken together, constitute what is known as the behavior of the organism, the protozoön is able to find food, to locate an optimum habitat, and to avoid injurious environments. Many parasitic PROTOZOA exhibit a sort of affinity for definite tissues. This may be largely due to the results of responses to stimuli.

3. MOTION AND LOCOMOTION

The possession of powers of motion and of locomotion makes it possible for PROTOZOA to take advantage of the stimuli received by them. Certain species may remain attached, and, by movements of the body, create currents which bring to it a constant supply of oxygen and of food particles, and that carry away from it the products of excretion and respiration. Other species appear to go in search of food and to flee from enemies, and no doubt the dispersion of the species is due largely to the powers of locomotion of individuals.

4. NUTRITION

PROTOZOA do not use as food any type of organic material that they encounter any more than do higher animals, but practice rather

definite food-selection. Thus one species may feed on bacteria and may seem to prefer certain types of bacteria, whereas others may feed on other PROTOZOA or, in the case of parasites, on red or white blood corpuscles. Free-living PROTOZOA in most cases ingest solid particles. These are usually obtained with the aid of pseudopodia, flagella or cilia. Frequently, as noted above, there is a special apparatus for the purpose of ingestion. The ingested food particles are suspended in liquid in a food vacuole into which the surrounding endoplasm secretes digestive enzymes. The products of digestion are liberated into the cytoplasm where assimilation occurs. Undigested particles are egested either through the general surface of the body or through a specialized opening, the cytopyge. Many PROTOZOA, especially among the parasitic species, do not ingest solid particles but absorb food from the medium in which they live directly through the surface of the body.

5. CIRCULATION

There is in the protozoan body no elaborate circulatory system, such as exists in certain higher animals, but movements occur in the protoplasm which serve to carry the digested food from one part of the body to another, and in some cases, for example, in *Paramœcium* and *Balantidium* a definite path is followed by the food vacuoles in their movements within the protoplasm. Protoplasmic movements no doubt also carry the injurious products of metabolism to the surface where they are expelled through the peripheral layer of ectoplasm.

6. RESPIRATION

Definite organs of respiration are also lacking in PROTOZOA, but oxygen is taken in through the surface of the body and carbon dioxide is expelled through the surface of the body, no elaborate structures being required for these purposes in such minute organisms.

7. SECRETION AND EXCRETION

As in higher animals, PROTOZOA must rid themselves of the excretory products of metabolism or they become poisoned. The excretory products are cast out either through the general body surface or in some species by the contractile vacuoles. Various secretion products of value are produced by PROTOZOA, such as material for the formation of skeletal and supporting structures, and enzymes for the digestion of food.

In the maintenance of the individual it is evident that the protozoön carries on all of the physiological processes characteristic of higher organisms. Jennings says of the simplest of all of the PROTOZOA, "If Ameba were a large animal, so as to come within the every day experience of human beings, its behavior would at once call forth the attribution to it of states of pleasure and pain, of hunger, desire, and the like, on precisely the same basis as we attribute these needs to the dog."

IV. *Maintenance of the Race*

1. REPRODUCTION

The power of reproduction is a fundamental property of protoplasm and successful reproduction is, of course, necessary for the maintenance of races of PROTOZOA. Although comparatively simple in structure and minute in size, the powers of reproduction of many PROTOZOA are exceedingly great. For example, it has been estimated that the ciliate *Paramœcium,* under favorable circumstances, could produce by binary fission from a single specimen 268,000,000 offspring in one month. This, no doubt, never happens since there are checks to multiplication, just as in higher organisms, which we designate by the phrase "the struggle for existence." Lack of space and of food and injurious physical and biological factors in the environment serve to keep down the numbers of specimens so that ordinarily a sort of equilibrium exists between any particular species of protozoön and the rest of the world.

Reproduction in the PROTOZOA is brought about by cell division. This may occur without the intervention of any sexual process, in which case it is known as asexual reproduction, or may involve the more or less intimate union of gametes which is characteristic of sexual reproduction.

2. ASEXUAL REPRODUCTION

Asexual reproduction may take place by binary fission, by schizogony or by budding. During binary fission the organism usually divides into two approximately equal daughters, each of which possesses one-half of the cytoplasm and one-half of the nucleus of the parent. Other organelles that may be present may arise anew in the daughter cells or the organelles of the parent may divide, one-half of each going to each daughter, or the parent organelle may go to one daughter and a similar organelle arise anew in the other daughter.

Nuclear division during binary fission is similar in most cases to mitosis in the cells of METAZOA but often occurs in what appears to be a more simple form. Thus one type of nuclear division is called promitosis. In this type the entire process takes place within the nuclear membrane; the karyosome divides into two, one passing to each end of the elongated nucleus and one-half of the chromosomes, which may or may not become arranged in equatorial plates, likewise migrate to each end of the nucleus. Then the nuclear membrane constricts in the center and the daughter nuclei finally separate. Mesomitosis is applied to a type of nuclear division that has probably evolved from promitosis. A mitotic figure and chromosomes occur but no polar caps are formed. Division takes place entirely within the nuclear membrane. In metamitosis all or most of the nuclear membrane breaks down. Amitosis, during which the chromatin in the nucleus appears to be simply constricted into two daughter nuclei without the formation of chromosomes, may occur in certain PROTOZOA, for example, in the case of the macronuclei of ciliates, but is not as prevalent in the PROTOZOA as formerly believed.

Budding is a type of asexual reproduction that occurs in certain PROTOZOA, particularly in the Class INFUSORIA. It has even been described in *Amœbæ,* for example, in *Councilmania lafleuri* (see page 60). The budding process involves the unequal division of a protozoön, one daughter being much smaller than the other. This difference in size is usually due to a difference in the quantity of the cytoplasm, since the nuclei of parent and bud are approximately of equal size.

The term schizogony is applied to a process which involves the repeated division of the nucleus without immediate cell division. This results in a multinucleate individual which eventually breaks up into a number of smaller uninucleate cells known as merozoites. This type of reproduction is particularly common among the SPOROZOA. The term schizogony is restricted to the formation of merozoites by a trophozoite, which is called a schizont. A type of multiple division resembling schizogony occurs also during sexual reproduction in certain SPOROZOA during which sporozoites are produced by a zygote following the fertilization process.

Many PROTOZOA have a cyst stage in their life-cycle during which the single original nucleus may divide into two, four or more nuclei. Just what happens when these cysts hatch is not fully known, but presumably as many daughter cells are formed as there are nuclei present. This is a type of asexual reproduction which may be called binary or multiple fission within a cyst wall.

3. SEXUAL REPRODUCTION OR SYNGAMY

Sexual processes frequently interrupt multiplication by asexual reproduction in the life-cycle. Syngamy is not really a type of multiplication but precedes certain types of multiplication. It involves either a temporary or permanent union of two cells which may be called gametes. A useful outline of the various methods by which syngamy is accomplished is given by Wenyon (1926) as follows:

1. Copulation: Complete union of two individuals
   - (1) Two individuals having the characters of the ordinary reproducing forms unite.
     - (a) The uniting forms are equal in size (isogamy).
     - (b) The uniting forms are unequal in size (anisogamy).
   - (2) Two individuals (gametocytes) give rise to a number of smaller forms (gametes) which unite in pairs.
     - (a) The gametes produced by the gametocytes are equal in size and characters (isogamy).
     - (b) The gametes produced by one individual are unlike those produced by the other (anisogamy).
       - (i) The number of gametes produced by the gametocytes are equal, or approximately equal, in number.
       - (ii) One gametocyte (macrogametocyte) gives rise to one large gamete (macrogamete), while the other (microgametocyte) gives rise to a variable number of small motile gametes (microgametes).
2. Conjugation: Two individuals (conjugants) associate, their nuclei divide, and exchange of daughter nuclei takes place, after which the conjugants separate.
   - (1) The conjugants are equal in size.
   - (2) The conjugants are unequal in size, one, a small one (microconjugant), associating with a large one (macroconjugant). In some cases, after interchange of nuclei the microconjugant degenerates.

These various types of syngamy will be referred to in later chapters in descriptions of the life-cycles of various species.

It has been shown briefly in this chapter how PROTOZOA maintain themselves and the race. PROTOZOA are able to live in all the major habitats. Free-living species are exceedingly abundant. Parasitic

PROTOZOA are likewise extremely rich in number of species since almost every other species of animal has its own species of protozoön living on or without it. Both free-living and parasitic PROTOZOA are also extremely rich in numbers of individuals. If we accept numbers of species and numbers of individuals as criteria of the success of any group of organisms we must acknowledge the superiority of the PROTOZOA in the struggle for existence among animals.

CHAPTER II

INTRODUCTION TO THE SARCODINA

I. *Classification*

As noted in the previous chapter the SARCODINA are characterized by the presence of pseudopodia. These are more or less temporary processes formed by the cytoplasm. They serve primarily for purposes of locomotion and for the capture and ingestion of food material. Some of the SARCODINA include in their life-cycle a flagellated stage. In the following table are listed some of the more important divisions into which the Class SARCODINA may be divided. Most of the parasitic species that are of particular interest with respect to man and his domesticated animals are included in a single family, the ENDAMŒBIDÆ.

Class SARCODINA. PROTOZOA with pseudopodia.

Subclass 1. RHIZOPODA. SARCODINA with lobose or reticulose pseudopodia; no axial filaments in pseudopodia; creeping forms.

Order 1. AMŒBIDA. RHIZOPODA with lobose pseudopodia; skeleton absent; simple shell may be present.

Suborder 1. GYMNAMŒBA. AMŒBIDA without skeleton or shell.

Family 1. AMŒBIDÆ. Free-living gymnamœbæ. Examples: *Amœba proteus, Pelomyxa palustris.*

Family 2. ENDAMŒBIDÆ. Parasitic in cavities or tissues. Examples: *Endamœba histolytica, Endolimax nana.*

Suborder 2. THECAMŒBA. AMŒBIDA with shell. Examples: *Arcella vulgaris, Chlamydophrys stercorea.*

Order 2. FORAMINIFERA. RHIZOPODA with reticulose pseudopodia; with shell. Example: *Polystomella crispa.*

Order 3. MYCETOZOA. RHIZOPODA with multinucleate plasmodium. Example: *Plasmodiophora brassicæ.*

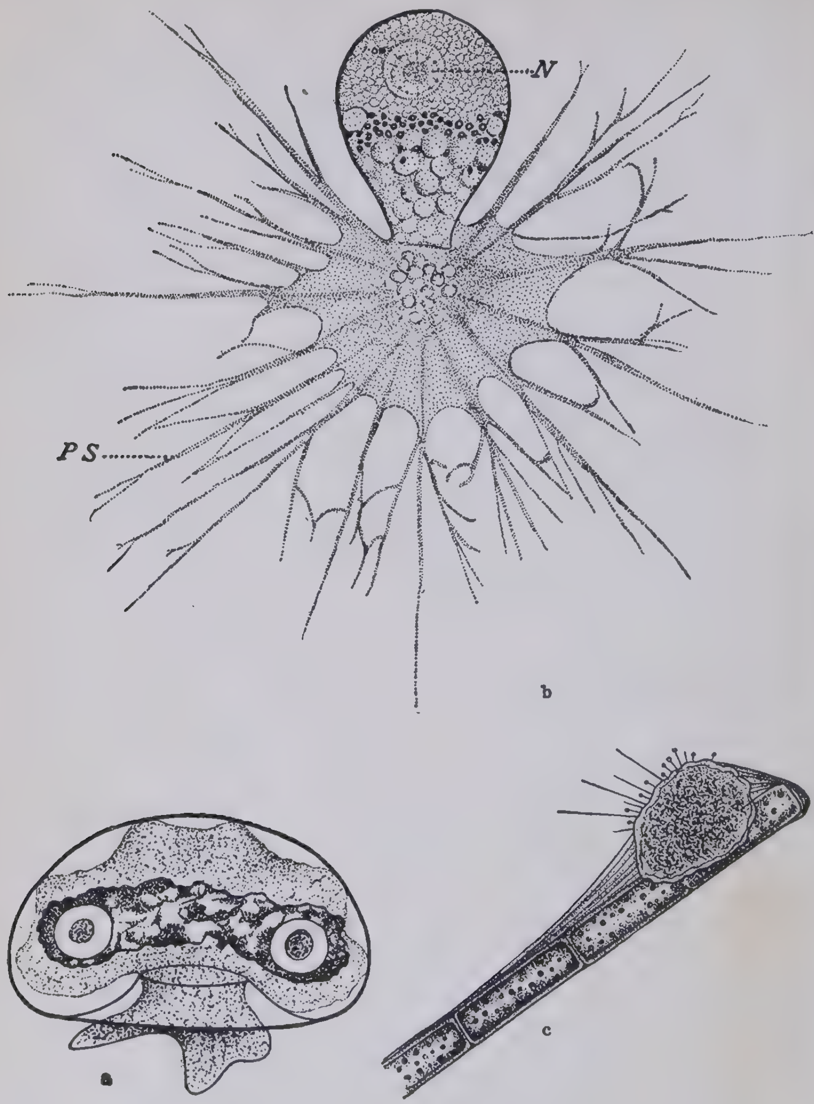


FIG. 3.—Types of SARCODINA.

a. *Arcella vulgaris*, a shelled free-living rhizopod. Side view showing protoplasmic body within shell, pseudopodia protruding from opening in shell, two nuclei, and dark chromidial mass (x 750). (After Wenyon)

b. *Chlamydophrys stercorea*, a coprozoic rhizopod. *N*, nucleus; *PS*, pseudopodia (x about 250). (From Calkins. After Schaudinn)

c. *Vampyrella lateritia*, a heliozoön attacking an alga (x 300). (From Wenyon. After Cash)

Subclass 2. ACTINOPODA. SARCODINA with radiating, unbranched pseudopodia; floating forms.

Order 1. HELIOZOA. ACTINOPODA with axial filament in pseudopodia. Example: *Actinophrys sol, Vampyrella lateritia.*

Order 2. RADIOLARIA. ACTINOPODA usually without axial filament; central capsule present. Example: *Thalassicola pelagica.*

II. *Amœba proteus*

Amœba proteus is the best known species in the Class SARCODINA. It is never a parasite, but lives in fresh water. A general view of the organism is shown in Figure 4 and a side view in Figure 5. These figures indicate the shape of the animal and the character of its pseudopodia. The clear area around the periphery represents the ectoplasm and the central granular area the endoplasm. In the endoplasm are located a biconcave nucleus, contractile vacuole, food bodies and crystals. Food is ingested with the aid of pseudopodia. *Amœba proteus* exercises a certain degree of choice with regard to food since it ingests certain types more frequently than others. The food particles are taken in at any point on the surface and undigested materials are egested at any point. The organism simply flows away from it. Excretion and respiration take place through the general surface of the body.

FIG. 4.—*Amœba proteus* in locomotion, showing nucleus, contractile vacuole, food bodies and longitudinal ridges (x 100). (After Schaeffer)

Amœba proteus reaches about 600 μ in length during locomotion. When this size is attained reproduction by binary division usually takes place. The nucleus divides by mitosis and then the cell-body divides into two approximately equal parts, each daughter amœba being supplied with a nucleus. Sporulation also occurs in amœbæ but has not often been observed. From five hundred to six hundred daughter nuclei are formed by successive divisions of the original nucleus but without divisions of the cell-body. A cyst wall surrounds this multinucleate stage. Very small amœbæ, called amœbulæ, arise

within the cyst and eventually break out as young amœbæ, which grow into the typical *Amœba proteus* in a few weeks.

As stated above, amœbæ move with the aid of pseudopodia. Many investigators have attempted to determine the method of amœboid movement. The latest and most plausible explanation is that offered by Mast (1926). Mast's explanation is too complicated to include

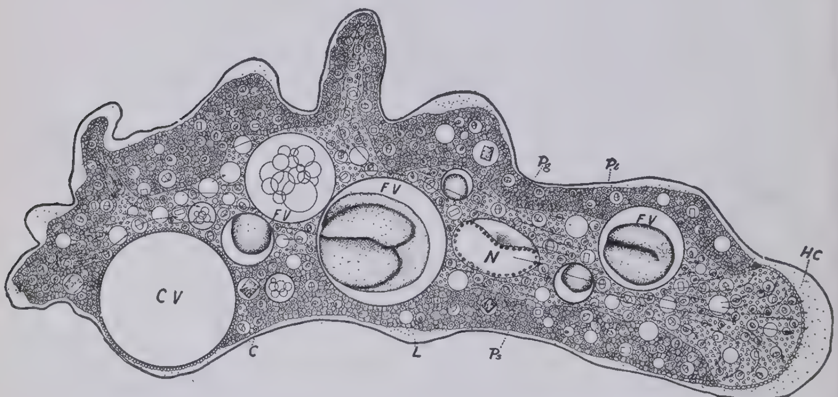


FIG. 5.—*Amœba proteus.* Horizontal optical section showing nucleus (N), contractile vacuole (CV), food vacuoles (FV), hyaline cap (HC), plasmagel (Pg), plasmasol (Ps), plasmalemma (Pl), liquid layer (L), and crystals (C). (After Mast)

here, hence reference should be made to the original article. *Amœba proteus* responds to various stimuli, reacting positively to some and negatively to others. In general it may be said that the responses are such as to be of value to the individual, since reactions are negative to such injurious agents as strong chemicals, heat and mechanical impacts, but positive to beneficial agents.

III. *Parasitic Sarcodina in General*

Almost every large group in the Class SARCODINA contains species of interest to parasitologists. The Order AMŒBIDA contains, as noted above, the Family ENDAMŒBIDÆ which includes most of the important species of SARCODINA that live in man and lower animals. These will be given special consideration in later chapters. In the Family AMŒBIDÆ are a number of interesting so-called coprozoic species belonging to the genera *Hartmannella*, *Vahlkampfia* and *Sappinia.* These will be described in Chapter III.

The Suborder THECAMŒBA besides many common fresh-water

species, includes a number of interesting coprozoic forms, especially *Chlamydophrys stercorea* (see Fig. 3b, page 36).

The FORAMINIFERA are fresh-water and marine organisms. The MYCETOZOA are terrestrial PROTOZOA living for the most part upon moist leaves and decaying wood. One of the best known species in this group is *Plasmodiophora brassicæ* which causes swellings on the roots of cabbages and other plants.

Several parasites of somewhat doubtful systematic position may be included in the Order HELIOZOA. *Vampyrella lateritia* (Figure 3c), for example, attacks algæ, into the cells of which it bores its way, grows and reproduces. Members of an allied genus, *Nuclearia,* are parasitic on both algæ and other PROTOZOA.

The marine PROTOZOA of the Order RADIOLARIA are of interest to parasitologists because many of them contain vegetable organisms known as ZOÖXANTHELLÆ which apparently live with the PROTOZOA in a state of symbiosis. Their yellow color frequently gives the protozoön this tinge on account of the large number of specimens present.

CHAPTER III

AMŒBÆ LIVING IN MAN

I. *Generic and Specific Characteristics*

Although the number of genera of amœbæ living in man has not been definitely established most protozoölogists agree that there are at least four, namely, *Endamœba, Endolimax, Iodamœba* and *Dientamœba.* These genera may be distinguished by the character of their nuclei.

As indicated in the figures, the endamœba nucleus possesses a small, more or less central, karyosome and a layer of granules on the nuclear membrane.

The endolimax nucleus contains a large karyosome frequently irregular in shape and consisting of several portions attached to each other by strands; often linin fibers extend from the karyosome to the nuclear membrane. There is no layer of chromatin granules on the nuclear membrane.

The nucleus of *Iodamœba* likewise lacks the peripheral chromatin granules; the single large karyosome is surrounded by a layer of faintly staining globules. As in *Endolimax,* linin fibers may extend from the karyosome to the nuclear membrane.

The genus *Dientamœba* is characterized, as the name implies, by the presence of two nuclei in many of the specimens; the chromatin in these consists of several granules imbedded in a matrix of plastin; this mass may be connected with the nuclear membrane by linin fibers.

The genus *Endamœba* is represented in man by three species. *Endamœba histolytica* lives primarily in the large intestine and secondarily in other parts of the body. The karyosome in the nucleus of this species is small and located in the center; the peripheral chromatin granules are delicate. *Endamœba coli* also lives in the large intestine; its nucleus has a larger karyosome eccentrically placed, and the chromatin granules on the nuclear membrane are coarse. The third species, *Endamœba gingivalis,* lives in the mouth. Its nucleus is not always spherical. The karyosome is usually subcentrally located and often consists of several granules; and the peripheral chromatin may be irregularly distributed.

The other three genera contain one species each that live in man. These are *Endolimax nana, Iodamœba williamsi* and *Dientamœba fragilis*. All of them live in the large intestine. Species belonging to the genera *Endamœba, Endolimax* and *Iodamœba* have been reported from many of the lower animals; some of these will be described in Chapter IV.

II. *Incidence of Infection*

The amœbæ that live in man seem to be cosmopolitan in their distribution, but the percentage of individuals among the general population that are infected varies in different localities. In general it may be said that the incidence of infection is apt to be higher in the warmer regions than in the colder parts of the world and in the less well sanitated areas than in communities where effective sewerage systems exist. In the United States the following estimates have been made of the percentage of infection among the general population: *Endamœba histolytica,* 10 per cent, *Endamœba coli,* 50 per cent, *Endolimax nana,* 25 per cent, and *Iodamœba williamsi,* 10 per cent. Our knowledge of the incidence of infection with *Endamœba gingivalis* is less definite but probably about 50 per cent are infected. *Dientamœba fragilis* is apparently rare, less than one hundred cases of infection having been reported to date. Fortunately *Endamœba histolytica* is the only one of these species whose pathogenicity has definitely been established and even this species does not bring about a diseased condition except under favorable circumstances, most of those who are infected being carriers.

III. *Endamœba histolytica*

I. HISTORICAL

There is some doubt as to who first saw and described *Endamœba histolytica.* Lewis (1870) described an intestinal amœba from man in a report on cholera in India. A more careful study of this species (Cunningham, 1871) indicates that it was probably *Endamœba coli.* There is no doubt but that Loesch saw *Endamœba histolytica* in a young Russian peasant in 1873 (published in 1875). Loesch demonstrated the pathogenic nature of this organism by infecting a dog with it; dysentery developed in the dog and amœbæ were found in ulcers in its intestine. Koch (in Koch and Gaffky, 1887), first saw amœbæ in intestinal sections made from patients who had died of dysentery. This stimulated the investigations by Kartulis who in

1887 described amœbæ in liver abscess pus and was the first to find this parasite in amœbic abscesses of the brain (Kartulis, 1904). Osler (1890) was the first to report *Endamœba histolytica* in America. He found the organism in liver abscesses and this discovery led to the important work of Councilman and Lafleur (1891) on the pathology of amœbic dysentery and amœbic abscess of the liver.

For many years it was supposed that only one species of amœba lived in the human intestine, but Councilman and Lafleur (1891) suggested that there might be two species and this was demonstrated by Quincke and Roos in 1893. The exact status of the two organisms now known as *Endamœba histolytica* and *Endamœba còli* was not finally decided until 1913 when Walker and Sellards' experiments on human beings demonstrated beyond question that *Endamœba histolytica* is pathogenic and produces cysts with four nuclei, and *Endamœba coli* is non-pathogenic and produces cysts with eight nuclei. Since 1913 many investigators have added to our knowledge of *Endamœba histolytica*. The results of these investigations are presented in the following paragraphs.

2. LIFE-CYCLE

This species is primarily a tissue parasite although it may be able to live in the lumen of the bowel without access to the intestinal wall. The active trophozoite divides by binary fission. In the human bowel, due to conditions still unknown, certain trophozoites may become smaller and lose their food inclusions; these are known as precystic forms. They become spherical and secrete a cyst wall about themselves and in this form pass out of the body in the feces. By two successive divisions the nuclei within the cyst increase from one to four. The infection of new hosts no doubt usually occurs by the ingestion of its infective cysts which probably hatch in the small intestine and liberate four small amœbæ. These then grow into adult trophozoites.

3. MORPHOLOGY

Trophozoite. The active or trophozoite stage of *E. histolytica* (Figure 6a) varies greatly in size but is usually from 20 μ to 30 μ in diameter. The size variations are due principally to two factors (1) growth following binary division and (2) heritably diverse size races. The clear ectoplasm around the periphery of the body may be distinguished from the more granular endoplasm; and the pseudopodia, which are entirely of ectoplasm, are thin and blade-like and

formed in an explosive manner. Within the cytoplasm are usually food vacuoles containing red blood cells, leucocytes or other tissue elements, and a single nucleus, which, however, is rarely distinctly visible in living specimens. The nuclear structure is revealed in fixed and stained preparations. The nucleus is of the endamœba type; it is from 4 μ to 7 μ in diameter; is "poor" in chromatin; and has a small, centrally located karyosome and a layer of fine chromatin granules on the nuclear membrane. Reproduction of the trophozoite is by binary fission. The nuclear membrane remains intact throughout. The number of chromosomes according to Kofoid and Swezy (1922)

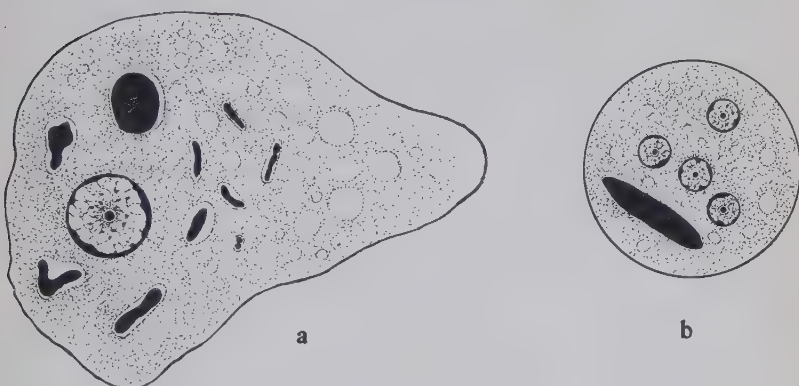


FIG. 6.—*Endamœba histolytica.* a. Trophozoite. b. Cyst (x 3000). (After Hegner)

is six (Figure 2b); these divide in the metaphase and migrate to the poles in the anaphase. Then the nucleus constricts into two.

Precystic stage. Before encysting, *E. histolytica* loses its food inclusions; decreases in size; becomes sluggish; and rounds up. Elmassian in 1909 believed this stage to be a distinct species and gave to it the name *Entamœba minuta.* Frequently vacuoles containing glycogen and rod-like refractile (chromatoid) bodies appear before encystment occurs.

Cyst. A thin peripheral wall is secreted by the precystic organism, thus forming a spherical body, the cyst (Figure 6b), which ranges from 5 μ to 20 μ in diameter. Different size races are indicated by differences in the size of the cysts. The mature cyst contains four nuclei, each of which appears like that of the trophozoite, but cysts with one, two and three nuclei are frequently passed. Often glycogen vacuoles and chromatoid bodies are present in young cysts, but these are usually absorbed later.

4. HOST-PARASITE RELATIONS

Epidemiology of transmission. The infection of new hosts is no doubt in most cases, as noted above, brought about by the ingestion of cysts. Certain experiments with guinea-pigs by Hegner (1926), however, indicate that trophozoites may be able to pass through the stomach and small intestine unharmed and set up an infection in the large intestine. It has been shown by Rivas (1926) that trophozoites may remain alive in fecal material for over twenty-four hours and Dobell and Laidlaw (1926) report that they will withstand 0.2 per cent hydrochloric acid for thirty minutes. Under culture conditions trophozoites may remain alive for three days at room temperature and at least five weeks at 37° C. (Dobell, 1927).

Cysts, when they are passed, may contain one, two, three or four nuclei. One patient may pass mostly uninucleate or binucleate cysts at one time and quadrinucleate cysts at another time; and cysts passed by different hosts may differ with respect to their nuclear number. It is generally believed that only the quadrinucleate cysts are infective, but Yorke and Adams (1927) have proved that cysts with one or two nuclei may continue to develop in culture media; such cysts may possibly develop to the infective stage after they have been ingested by a new host.

The successful infection of new hosts depends to a considerable extent upon the viability of cysts outside of the body. Moisture is necessary for long continued existence since, although protected with a resistant wall, drying is soon fatal to them. The distribution of viable cysts in a dried condition is, therefore, impossible. Various tests have been used to determine the viability of cysts. The method most frequently used is the addition of eosin in a concentration of 1 : 1000. This is supposed to penetrate and stain dead cysts but not those that are alive. This method is not entirely satisfactory. It is now possible to cultivate *Endamœba histolytica* in artificial media and under proper conditions excystation occurs. In this way the viability of cysts can be determined without question. Perhaps the best method of proving viability is to use laboratory animals such as kittens; but this method is far from simple.

Cysts in nature remain in the feces in latrines until they die or are carried away by flies and other animals, or on the surface of the soil where they are destroyed by drying, are disseminated by animals or washed into the soil or into ponds and streams by the rain. The viability of cysts in raw and diluted feces and the probability of their

dissemination by flies and other animals are thus subjects of public health importance.

It has been found that when cysts remain in moist feces they may live for several weeks. Dilution of the feces with water seems to be favorable for their continued existence. Cysts are able to withstand a wide range of temperatures, for example, Yorke and Adams (1926) were able to obtain cultures from cysts that had remained in raw feces at room temperature for nine days, and in water at 0° C. for seventeen days; and Dobell (1927) states that cysts may remain alive at room temperature for as long as 37 days but usually only a few days at 37° C. The pasteurization of milk probably raises the temperature to a high enough point (60° C.) for a sufficient time to destroy any cysts that may be present and of course bringing water to the boiling point accomplishes the same result. Various experiments have been reported with disinfectants; these indicate that cresol in a strength of 1 : 20 kills the cysts almost instantly.

There is only one conceivable way in which new hosts can be infected and that is by the ingestion of viable cysts. It seems probable that cysts usually reach the mouth in contaminated food and drink, although they might also be carried there on soiled hands. Among the most important factors that bring about the dissemination of cysts are probably the handling of food by infected persons, the common use of toilet, wash bowl, and towel and dissemination by insects and perhaps other animals. It has been shown that house-flies will ingest large numbers of cysts at a single meal and that these may be deposited on food or in drink in a living condition in the feces of the fly from five minutes to at least sixteen hours after feeding. Flies no doubt play a rôle in the dissemination of *Endamœba histolytica*. Other animals are probably less important. Ants and cockroaches are possible distributing agents. Several investigators have shown that rats and mice may become infected, but these animals probably play a minor rôle in transmission.

As pointed out above, most hosts infected with *Endamœba histolytica* are carriers, that is, they are infected and are passing cysts but do not exhibit any symptoms of disease. Carriers are particularly dangerous since in them the infective cysts are formed, whereas patients suffering from acute amœbic dysentery pass only the non-infective trophozoites. It has been suggested that carriers among certain classes of people, such as food-handlers, be eliminated by treatment but this is at present impracticable.

An interesting fact regarding the epidemiology of amœbiasis is

the greater number of acute cases that occur in the Tropics as compared with the temperate regions. Three principal reasons have been offered to account for this; climate, lack of sanitation and the presence of more virulent strains. None of these, however, has been demonstrated. Epidemics of amœbiasis have been reported by several, but are certainly uncommon.

An important fact that has been brought out by studies on the transmission of protozoan cysts is that the host is entirely responsible for his own infection. The parasite remains passive while in the infective stage and can only reach the intestine of a new host by the activities of that host.

Parasitological and clinical periods. The prepatent period in infections in man with *Endamœba histolytica,* according to the work of Walker and Sellards (1913), ranges from one to forty-four days, that is, cysts were recovered from the stools of patients from one to forty-four days after they had swallowed gelatin capsules containing infective cysts. The prepatent period in most of these cases was four or five days. The patent period may last for years, the infected person becoming a carrier. Walker divided carriers into two types, contact carriers who have never exhibited symptoms and convalescent carriers who pass cysts after recovering from an attack of dysentery. Carriers frequently suffer relapses during which symptoms reappear. The incubation period in Walker's experiments ranged from twenty to ninety-five days. In cats, which are very susceptible to infection, the incubation period lasts about two weeks if cysts are injected per os but only about two days if rectal injections of trophozoites are given.

Distribution and localization within the host. Since the primary site of infection of *Endamœba histolytica* is the large intestine, cysts that are ingested by a host must pass through the stomach and small intestine. Cysts have no powers of locomotion, hence they are passively carried along in the stomach and intestinal contents. They may reach the large intestine within four hours. Where excystation occurs is not known. It is generally believed that this takes place in the small intestine, but recent work by Sellards and Theiler (1924), Kessel (1923) and Hoare (1925) indicates that cysts may hatch in the large intestine.

For many years it has been supposed that cysts do not develop outside of the body but that they require the stimuli furnished by digestive juices for excystation. It has been found by Yorke and Adams (1926, 1927) and Dobell (1927) that uninucleate and binucleate cysts develop to the quadrinucleate stage in culture media

incubated at 37° C., and that mature cysts excyst under such conditions. Apparently moisture and a suitable temperature are the only factors necessary to bring about excystation. There seems to be some inhibiting substance, however, in the intestinal contents of the host that prevents the hatching of the cysts in the host in which the cysts are formed (Yorke and Adams, 1927). The evidence at present available indicates that a four-nucleated amœba emerges from the cyst and subsequently divides into four uninucleate amœbæ.

Primary site of infection. The amœbæ that escape from the cysts and succeed in reaching the intestinal wall may establish themselves in the large intestine, which is the primary site of infection. No doubt many cysts and many excysted amœbæ are carried out of the body in the feces. Those parts of the intestine where stasis is first encountered are most frequently infected. This is indicated by the experimental work of Sellards and Theiler (1924) on kittens and by the results of post-mortem examinations on human beings. Clark (1924), for example, shows (Figure 7) that in a total of 186 cases, ulcers were scattered throughout the colon in 113 cases (60.7 per cent), but in 63 cases (33.8 per cent) were limited to certain regions. These regions, as indicated in Figure 7, are dependent portions where greatest stasis occurs, that is the cecum, ascending colon, rectum, sigmoid and appendix.

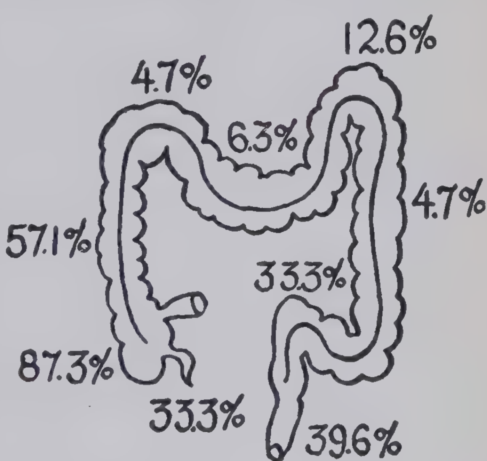


FIG. 7.—Appendix, colon and rectum of man showing the regional distribution of lesions in sixty-three cases of amœbic dysentery. (After Clark)

Secondary sites of infection. Amœbæ may migrate from the large intestine into the ileum but very few cases of this type have been reported. Amœbæ may also gain entrance to the blood stream by way of the ulcers in the intestinal wall and may be carried to various parts of the body. They may set up infections wherever favorable conditions exist. The most frequent secondary site of infection is the liver. In this organ they produce abscesses, most often in the right lobe, and sometimes so large that they contain over a gallon of pus,

These abscesses may rupture into the lung. Amœbic abscesses occur in a large proportion of patients who die of amœbic dysentery. For example, Kartulis (1887) noted 55 per cent in 500 cases at autopsy, Craig (1911) records 33 per cent of seventy-eight cases and Clark (1924) reports 51 per cent of 186 cases. Abscesses of amœbic origin may also occur in the lung, brain and spleen. Certain investigators believe that *Endamœba histolytica* is responsible for various diseased conditions of obscure etiology.

Pathogenesis. Endamœba histolytica is primarily a tissue parasite and as such is always pathogenic to the host although, as noted above, very few persons who are infected exhibit symptoms but are in the carrier condition. Apparently in such cases a state of equilibrium between parasite and host is attained during which the injuries caused by the amœbæ are repaired by the host tissue as rapidly as they are produced. When the host is not able to repair the lesions as rapidly as they are caused symptoms appear. The most common symptom of intestinal amœbiasis is diarrhea. This is frequently followed by dysentery. Other symptoms occur when the invasion of other organs, such as the liver and brain, takes place.

Amœbæ are supposed to invade the tissues of the intestinal wall by dissolving away the cells with the aid of a cytolytic ferment which they secrete, or by pressure due to their rapid multiplication and the consequent blocking of the opening of the glands into which they have migrated. They do not appear to ingest red blood cells or other tissue elements while within the tissues. Continued multiplication of the amœbæ and cellular destruction leads to the formation of a nodule which eventually bursts into the intestinal lumen, thus producing an ulcer. Some of the amœbæ that escape invade neighboring glands and repeat the process, thus spreading the infected area. At the same time, those that remain in the ulcer continue the destruction of the tissues at the sides and bottom. Further pathological effects result from a continuation of this process. These tissue-invading amœbæ are large and never of the precystic type; the latter, as well as cysts, occur only in the lumen of the intestine.

Immunology. The evidence available indicates that an age immunity exists in both man and lower animals to infections with *Endamœba histolytica.* Young kittens, for example, are more susceptible and suffer a more acute attack than older animals. There is some evidence also that some races are more resistant to infection than others. For example, Fletcher and Jepps (1924) recorded 19.1 per cent of infection among Tamils and only 5.6 per cent among Chinese.

Several attempts have been made to perfect a complement fixation

test in amœbiasis. The most recent is that of Craig (1927, 1928). Craig found cytolytic and complement binding substances in absolute alcohol extracts of forty-eight-hour old cultures of *Endamœba histolytica;* the complement fixation substance was apparently specific for *Endamœba histolytica* since the blood sera of individuals infected with other species of amœbæ gave negative reactions. Wagener (1924) seems to have obtained some success in perfecting a precipitin test in cats using antigen from scrapings of ulcerated areas of infected animals; and Scalas (1923) claims to have worked out an intradermal reaction for man using antigens prepared from the fresh feces of a case of acute dysentery.

Changes may take place in the aggressivity of the parasite as well as in the resistance of the host, but apparently whether a host becomes a carrier or suffers an acute attack depends on the physiological condition of the host and not on the virulence of the amœbæ. For example, Walker and Sellards (1913) fed cysts from a convalescent carrier to a fresh host who became a contact carrier; cysts from this contact carrier when fed to a third person produced another contact carrier; but cysts from this third case when fed to a fourth individual brought about an attack of dysentery three weeks later. These facts indicate that the fourth person in this series was less resistant rather than that the virulence of the parasite changed.

Host-parasite adjustments. The presence of parasites in a host without the appearance of symptoms is often spoken of as latency. How long a carrier condition or period of latency may last is not known, but it seems probable that an infection once established persists for many years and possibly even throughout the life of the host. Carriers, however, are liable to exhibit symptoms at any time; such an occurrence is spoken of as a relapse. Just what modifications in the host or parasite are responsible for relapses is not known with certainty.

There are three principal points of view with regard to the character of the host-parasite relations during the carrier period. The amœbæ may live as harmless commensals in the lumen of the intestine although this does not seem probable; amœbæ may attack the tissues of the intestinal wall but not severely enough to bring about symptoms; or the amœbæ may, by their invasion of the tissues, bring about what is known as chronic amœbiasis. Kofoid (1923), Boyers, Kofoid and Swezy (1925), Acton and Knowles (1924) and Craig (1927) are among those who believe that amœbæ, during the carrier condition, bring about in their hosts recognizable symptoms. Further study of this subject is necessary before a final conclusion is possible.

5. PREVENTION AND CONTROL

Amœbiasis is a preventible disease just as are bacillary dysentery, typhoid fever and similar diseases. Acute cases are not dangerous since no infective cysts are passed by them. Carriers, however, may pass as many as 300,000,000 cysts in a single day (Kofoid, 1923). The control of carriers and the transmitting agents, or the destruction of cysts after they are passed, are obvious methods of preventing the spread of amœbiasis. Individuals may be protected by preventing the contamination of their food and drink. In certain countries, such as China, where night-soil is used as fertilizer, vegetables and fruit should not be eaten until they have been immersed in water at 80° C. for ten seconds (Mills, Bartlett and Kessel, 1925). Community efforts for prevention and control should be directed primarily toward improvements in the water supply, milk supply and general sanitation. The effect of a change in the water supply is shown in statistics furnished by Clark (1924). Clark found in Panama, among 4,000 autopsies from 1905 to 1914, 170 cases of amœbiasis or 4.25 per cent. A better water supply was then furnished and during the period 1914 to 1923 among 2,800 autopsies only sixteen cases or 0.57 per cent of amœbiasis were reported. A recent analysis of methods of treatment of amœbiasis is that published by Knowles (1928).

6. HOST-PARASITE SPECIFICITY

Endamœba histolytica is a natural parasite of man. Spontaneous infections with this species have been reported in cats, dogs and monkeys but these were probably brought about by the ingestion of cysts passed by man. Experimental infections have been obtained in monkeys, cats, dogs, rats, mice, guinea-pigs and rabbits. Monkeys seem to be infected in nature with an amœba resembling *Endamœba histolytica,* but it is not yet known whether it is the same or a different species. Kittens may be infected very easily in the laboratory; older cats and dogs are more difficult to infect. Both these animals and monkeys have been found to suffer from amœbic liver abscess. Kessel (1923) was the first to successfully infect rats and mice. Baetjer and Sellards (1914) and Chatton (1917, 1918) are the only ones to report successful infections in guinea-pigs. Rabbits have been infected by Huber (1909) and Thomson (1926). Monkeys, rats and mice that are infected may pass cysts, but kittens undergo an acute infection without the passage of cysts and thus far no cysts have been observed in guinea-pigs and rabbits.

IV. *Endamœba coli*

1. HISTORICAL

As previously stated, *Endamœba coli* was first reported by Lewis in 1870 and more accurately described by Cunningham (1871). Accounts of it were later given by Grassi (1879), by Quincke and Roos (1893) and by Casagrandi and Barbagallo (1895, 1897), Schaudinn (1903) distinguished definitely between *Endamœba coli* and *Endamœba histolytica,* and recognized the former to be non-pathogenic and the latter pathogenic. Because a pathogenic organism is more interesting than a non-pathogenic species, more work has been done on *Endamœba histolytica* than on *Endamœba coli.*

2. LIFE-CYCLE

The life-cycle of *Endamœba coli* is similar to that of *Endamœba histolytica* except that the organism lives only in the lumen of the intestine and does not invade the tissues. The trophozoite may pass through the precystic stage and produce cysts in which, by three successive divisions, eight nuclei are formed. Cysts pass out of the body and bring about new infections if they are ingested by a susceptible host.

3. MORPHOLOGY

Trophozoites. The trophozoites of *Endamœba coli* (Figure 8a) are never very abundant in a particular host, as is true of *Endamœba histolytica.* They live in the large intestine. In size they range from 18 μ to 40 μ, being usually from 20 μ to 30 μ in diameter; they are thus of about the same mass as *Endamœba histolytica.* The distinction between endoplasm and ectoplasm is not well marked. Pseudopodia are granular and not clear as in *Endamœba histolytica,* and are formed slowly rather than explosively as in the latter. Movement is sluggish. The nucleus, which is generally visible in the living animal, contains a rather large karyosome eccentrically placed and a thick layer of chromatin granules on the nuclear membrane. The food of *Endamœba coli* consists of organic material in the intestine, but red cells and tissue elements are not ingested. The trophozoite of *Endamœba coli* reproduces by binary fission.

Precystic stage. The precystic stage is accompanied by the casting out of food bodies and the assumption of a spherical shape. The precystic stage of *Endamœba coli* can be distinguished from that of *Endamœba histolytica* by the difference in the nuclear structure.

Cysts. The cysts of *Endamœba coli* (Figure 8b) range from 10 μ to 30 μ or more in diameter. Size is a criterion that cannot be used with certainty to distinguish this species from *Endamœba histolytica,* but cysts less than 10 μ in diameter are usually those of *Endamœba histolytica,* whereas cysts more than 20 μ in diameter are usually those of *Endamœba coli.* From one to eight nuclei ordinarily are present in the cysts, although as many as twenty have been reported. The normal mature cyst contains eight nuclei. Mitosis within the cyst (Figure 2a) has been described by Swezy (1922). It occurs within the nuclear membrane and the chromosome number is six. In

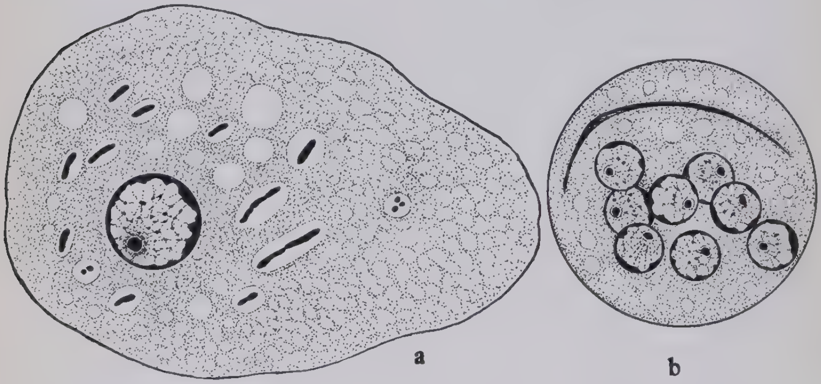


FIG. 8.—*Endamœba coli.* a. Trophozoite. b. Cyst (x 3000). (After Hegner)

young cysts, glycogen bodies occur; these are usually larger than similar bodies in *Endamœba histolytica.* Chromatoid bodies also occur in the cyst; these are splinter-like and often in bundles, and do not have blunt rounded ends as do those of *Endamœba histolytica.* They gradually disappear as the cysts increase in age.

4. HOST-PARASITE RELATIONS

The transmission of *Endamœba coli* from one host to another is no doubt brought about by the contamination of food or drink with feces containing cysts, and the factors that are responsible for the dissemination of the cysts are similar to those described for *Endamœba histolytica.* The cysts are finally carried through the stomach and small intestine, where they probably hatch, and thence into the large

intestine. Excystation has been observed outside of the body (Yoshida, 1920; Hegner, 1927), but nothing is known of this process within the host. There is no good evidence that *Endamœba coli* invades the tissues, hence its host-parasite relations are very simple. At least 50 per cent of the general population appear to be infected with this species indicating the prevalence of the fecal contamination of human food and drink. Why *Endamœba coli* should be more successful than *Endamœba histolytica,* which infects only about 10 per cent of the general population, has not been determined.

5. HOST-PARASITE SPECIFICITY

That man is a good host for *Endamœba coli* was demonstrated by Walker and Sellards (1913) ; of twenty men who were fed cysts from five different hosts seventeen became infected; none of these exhibited symptoms. An amœba resembling *Endamœba coli,* and which may be identical with it, has been reported from monkeys. Kessel (1923) reported the infection of rats with *Endamœba coli* and the following year the experimental infection of monkeys (Kessel, 1924).

V. *Endamœba gingivalis*

1. HISTORICAL

This species appears to be the first entozoic amœba of any animal to be discovered, and the first amœba of man to be described. Gros (1849) reported amœbæ from the tartar of the teeth of man which must have been this species. It was reported by Steinberg (1862), by Grassi (1879) and by others at intervals up to the year 1915 when Smith and Barrett and Bass and Johns decided that this species is a tissue invader and the probable etiological agent of *pyorrhea alveolaris*. These publications brought the organism into great prominence and resulted in the stimulation of numerous investigations.

2. LIFE-CYCLE

So far as is known, *Endamœba gingivalis* occurs only as a trophozoite, no cyst ever having been found. Multiplication is by binary fission. There is probably no life outside the body of the host, the amœbæ being passed directly from one host to another.

3. MORPHOLOGY

The trophozoites of *Endamœba gingivalis* (Figure 9) range from 6 μ to 60 μ in diameter but are rarely over 20 μ. The clear ectoplasm is distinct from the granular endoplasm and locomotion is fairly active. Kofoid and Swezy (1924) describe a distinct pellicle. The nucleus is of the endamœba type, smaller than that of *Endamœba coli* and with a karyosome either centrally located or eccentric. The food vacuoles contain bacteria, leucocytes and the like; red cells have rarely been reported.

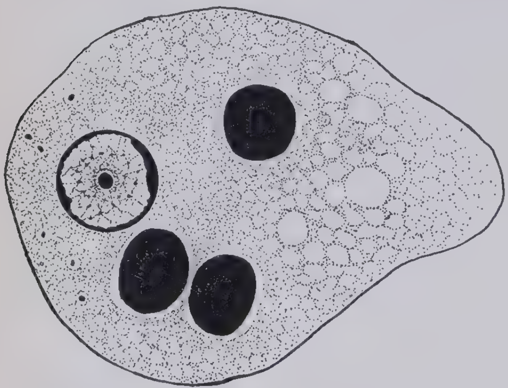


FIG. 9.—*Endamœba gingivalis.* Trophozoite (x 3000). (After Hegner)

4. TRANSMISSION

The transmission of *Endamœba gingivalis* from host to host no doubt takes place in the trophozoite stage and plenty of opportunity is afforded for direct passage during kissing. It is thus easy to account for the high incidence of infection in the general population which probably averages at least 50 per cent. The absence of a cyst stage in an amœba that is transmitted by direct contact is worthy of note.

5. PATHOGENICITY

E. gingivalis lives in various places in the mouth, but especially in the tartar of the teeth and in the materia alba around them; it has been reported from many suppurative and inflamed conditions of the mouth and throat. That this species does not require access to the tissues is indicated by the fact that Lynch (1915) found them in the crevices between the false teeth of persons with healthy gums. Various new species have been described from abscesses in the jaw and tonsils, but these were probably all somewhat modified *E. gingivalis.* The presence of large numbers of these amœbæ in the lesions of *pyorrhea alveolaris* led Smith and Barrett (1915) and Bass and Johns (1915) to conclude that they are responsible for this disease, and on their recommendation emetin was widely used in its treatment. More

recent studies indicate that the species is harmless. Its food consists principally of leucocytes and a few bacteria (Kofoid and Swezy, 1924). Smith and Barrett (1915) record the ingestion of red cells and Howitt (1926) finds that washed red cells of the guinea-pig are eaten by specimens in artificial cultures, but erythrocytes are probably very seldom devoured in nature. The colonization of the intestine by this species as a result of swallowing trophozoites seems impossible according to the work of Howitt (1926), who found that they were unable to withstand human gastric juice containing the normal amount of acid, and quickly exploded when subjected to human bile.

6. HOST-PARASITE SPECIFICITY

Amœbæ have been found in the mouths of certain lower animals. Goodrich and Moseley (1916) reported them from the dog and cat suffering from pyorrhea, and Nieschulz (1924) described what he considers a variety of the human species *E. gingivalis* var. *equi* from around the teeth of the horse. It remains to be determined whether these are specifically distinct from the form occurring in man. Hecker (1916) found it impossible to infect guinea-pigs with amœbæ from the human mouth and Drbohlav (1925) was equally unsuccessful with a kitten into the intestine of which he injected specimens grown in culture, and with a young dog into the gingivæ of which similar material was inoculated. Hinshaw (1928), however, reports the successful inoculation of dogs with *E. gingivalis* from man.

VI. *Endolimax nana*

1. HISTORICAL

This species was seen by various observers during the early years of this century but was not recognized as a separate species until 1917 when Wenyon and O'Connor found it to be a common inhabitant of human beings in Egypt. It has since been widely studied and is now known to be one of the commonest of human amœbæ being present in about 25 per cent of the general population.

2. LIFE-CYCLE

The life-cycle of *Endolimax nana* resembles that of *Endamœba coli*. Trophozoites live in the lumen of the large intestine where they feed on organic material; precystic stages occur, which develop into

cysts; these pass out of the body in the feces and bring about infections if ingested by susceptible hosts.

3. MORPHOLOGY

Trophozoite. This is a comparatively small species, the trophozoite (Figure 10a) measuring only 6 μ to 12 μ in diameter. It has clear, blunt pseudopodia but is usually sluggish. The food vacuoles contain bacteria and other food bodies. The nucleus is like that characteristic of the genus.

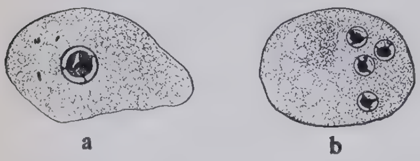


FIG. 10.—*Endolimax nana.* a. Trophozoite. b. Cyst (x 3000). (After Hegner)

Precystic stage. As in *E. histolytica* and *E. coli* the precystic stage loses its food bodies, but does not become much smaller than the adult trophozoite.

Cyst. The cysts (Figure 10b) are typically ovoidal, but sometimes are spherical or irregular in shape. They are from 8 μ to 10 μ in length and about 6 μ in breadth. The fully developed cysts contain four nuclei but younger cysts with one, two or three nuclei occur. No chromatoid bodies are present but diffuse glycogen masses may occur from the precystic to the four-nucleate stage.

4. HOST-PARASITE RELATIONS

Endolimax nana is probably a harmless commensal living in the large intestine. Transmission no doubt occurs in the cyst stage and differs in no essential feature from that described for *Endamœba histolytica.* Excystation *in vitro* has been described by Hegner (1927) but has never been seen in the living animal. There is no evidence of pathogenicity. Kessel (1923) claims to have infected rats by feeding them cysts from man and also reports positive results with monkeys (1924).

VII. *Iodamœba williamsi*

1. HISTORICAL

Cysts of this species were first described by Wenyon (1915, 1916) as "iodine cysts" because of the presence of a glycogen mass which stains a dark reddish-brown in iodine solution. Kuenen and Swellengrebel (1917) reported both cysts and trophozoites in a case and

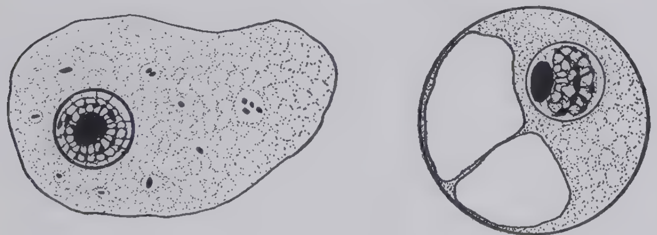
Brug (1919) concluded that the "iodine cysts" represent the encysted stage of this amœba. There is some question as to the specific name; certain protozoölogists believe that this is the organism found by Prowazek (1912) in a child and named *Entamœba bütschlii,* whereas others believe (Taliaferro and Becker, 1922) that it represents the amœba described by Prowazek (1911) as *Entamœba williamsi.* The genus name, *Iodamœba* was coined for it by Dobell (1919).

2. LIFE-CYCLE

This amœba is an inhabitant of the lumen of the intestine of man and is present in about 10 per cent of the general population. The trophozoites multiply by binary fission; a precystic stage occurs and uninucleate cysts are formed.

3. MORPHOLOGY

Trophozoite. This is generally from 9 μ to 14 μ in diameter, although specimens have been reported that were smaller or larger



a b

FIG. 11.—*Iodamœba williamsi.* a. Trophozoite. b. Cyst (x 3000). (After Hegner)

(Figure 11a). There is no clear distinction between ectoplasm and endoplasm. Locomotion is sluggish. The endoplasm is usually crowded with food vacuoles containing bacteria and intestinal débris but no red cells. The nucleus is like that characteristic of the genus.

Precystic stage. As in other species the trophozoites before encysting lose their food vacuoles, but they decrease very little in size.

Cyst. The cysts (Figure 11b) are spherical or irregular in shape and measure from 6 μ to 16 μ in diameter, averaging about 9 μ. They contain a single nucleus except on rare occasions when two are present. The karyosome of the nucleus lies on one side and the rest

of the space is filled with globules. Large glycogen vacuoles are seldom absent from the cysts. No chromatoid bodies are present.

4. HOST-PARASITE RELATIONS

Iodamœba williamsi appears to be a harmless commensal feeding on bacteria and organic matter in the large intestine. Transmission probably takes place in the cyst stage as in *E. histolytica, E. coli* and *Endolimax nana.* Smith (1927) has described excystation *in vitro* in guinea-pigs. Apparently moisture and a suitable temperature are the required stimuli; cysts in a weak saline solution on a slide under a cover-glass, when maintained at a temperature of 37° C. for about five hours, were seen to excyst on a number of occasions. When injected into the stomach of guinea-pigs, cysts are carried into the small intestine where they may excyst in the jejunum within a period of three hours. Kessel (1923) and Smith (1928) appear to have brought about infections in rats with cysts from man. It is possible that amœbæ belonging to this genus that have been reported from lower animals may belong to the same species as that from man.

VIII. *Dientamœba fragilis*

1. HISTORICAL

Only one species of the genus *Dientamœba* is known; this occurs in man and was described by Jepps and Dobell (1918) as *Dientamœba fragilis* because of its apparent delicacy. It has been recorded from less than one hundred cases. Its method of reproduction has not been described.

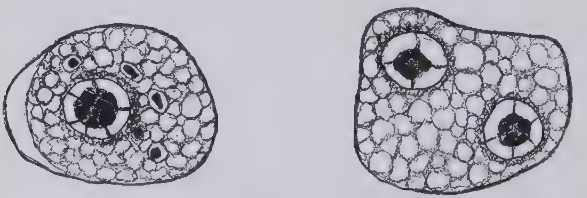


FIG. 12.—*Dientamœba fragilis.* One specimen uninucleate and the other binucleate (x 4300). (After Taliaferro and Becker)

2. MORPHOLOGY

Trophozoite. This rare species (Figure 12) is only 3.5 μ to 12 μ in diameter. It is active, has clearly defined ectoplasm and endoplasm,

and sends out leaflike, hyaline pseudopodia. Two nuclei with the characteristics already described are usually present although specimens with one nucleus are not uncommon. The food consists of bacteria and yeasts.

Cyst. Only one observer has noted cysts (Kofoid, 1923). These are "spherical with glycogen vacuoles and small chromatoidal bodies."

3. HOST-PARASITE RELATIONS

The rarity of cysts of *Dientamœba fragilis* and the apparent delicacy of the trophozoites probably account for the small number of infections that have been noted; in fact, it seems strange that this species can continue to exist. It has been suggested that man is not the "normal" host of *D. fragilis,* but no one has yet discovered this or similar species in any lower animal. Obviously no discussion of its host-parasite relations is possible until further data are obtained.

IX. *Doubtful Species of Amœbæ Reported from Man*

The six species of amœbæ described above are recognized as "good" species by practically all protozoölogists. Besides these almost one hundred other species have been described as human parasites but have not become established as distinct species. Most of these doubtful forms have been described by persons who were careless in their work or knew very little about protozoölogy. Several stages in the life-cycle of a single species have sometimes been described as distinct species, and in some cases stages in the life-cycle of several species have been combined under one specific name. Of all these doubtful species only four need be considered here. These are *Councilmania lafleuri* described by Kofoid and Swezy in 1921, *Caudamœba sinensis* described by Faust in 1923, *Karyamœbina falcata* described by Kofoid and Swezy in 1924 and *Endamœba dispar* named by Brumpt in 1925.

Councilmania lafleuri. This species was found by Kofoid and Swezy in the stools of ten persons during the period July 1920 to June 1921 and several of Kofoid's students have carried on work with it, notably Kessel (1923) who claims to have obtained infections in rats and mice by feeding them cysts, Bercovitz (1924) who studied the effects of disinfectants on its cysts and Allen (1926) who has described excystation in this species in culture media. Kessel (1924) believes that two species of amœbæ living in rats belong to this genus, namely, *C. decumani* and *C. muris.*

According to Kofoid and Swezy the genus *Councilmania* differs from other genera of amœbæ that live in man in (1) the presence of a karyosome in the nucleus that is surrounded by a sort of halo or that is in premitosis and consists of more or less dispersed granules; (2) the granules on the nuclear membrane are fine; and (3) buds are produced by the cyst during which process a chromophile ridge appears. The cysts differ from those of *Endamœba histolytica* in the possession of eight instead of four nuclei. The species differs from *Endamœba coli* in (1) the habit of ingesting red blood cells; (2)

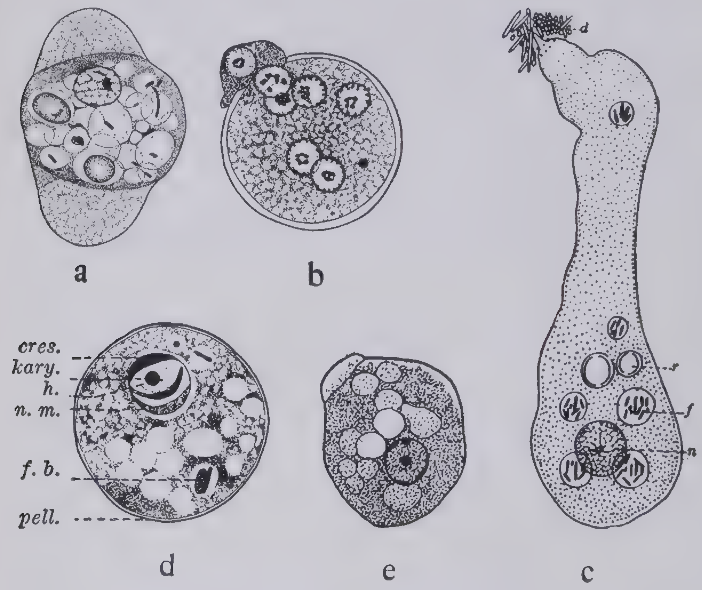


FIG. 13.—Doubtful species of amœbæ reported from man.
a. *Councilmania lafleuri.* Trophozoite (x 800). (After Kofoid and Swezy)
b. *Councilmania lafleuri.* Cyst, budding (x 800). (After Kofoid and Swezy)
c. *Caudamœba sinensis.* Trophozoite. *n.*, nucleus; *f.*, food vacuole; *r.*, red blood cell; *d.*, débris attached to caudostyle (x 2000). (After Faust)
d. *Karyamœbina falcata.* Trophozoite. *cres.*, crescentic body on nuclear membrane; *kary.*, karyosome; *h.*, halo around karyosome; *n.m.*, nuclear membrane; *f.b.*, food body; *pell.*, pellicle (x 1500). (After Kofoid and Swezy)
e. *Endamœba dispar.* Trophozoite (x 1500). (After Brumpt)

the formation of clear explosive pseudopodia; (3) the appearance of eight instead of six chromosomes during mitosis; and (4) a thick cyst wall.

Councilmania lafleuri has not been widely accepted as a distinct species. For example, Wenyon (1925) considers it an aberrant form

of *E. coli;* Craig (1926) describes it among forms of uncertain or doubtful status; and Calkins (1926) places a question mark after it. Detailed criticisms have been published by Gunn (1922) and Wight and Prince (1927). It seems best at present, therefore, to consider this new genus and species of uncertain status. Two new species of amœbæ belonging to this genus have recently been described from man by Kofoid (1928); these are *C. tenuis* and *C. dissimilis.*

Caudamœba sinensis was observed by Faust (1923) in four cases of dysentery in Peking. It is characterized by a definite fixed polarity, the anterior end being broadly lobose and containing the nucleus and the posterior end being thin with a caudostyle often with débris attached to it. Pseudopodia are rare. No division was observed and no cysts were found. Infections were cured with emetine. It has been suggested (Wenyon, 1925) that this is an aberrant form of *E. histolytica.* It has also been suggested that it may be a degenerate *Trichomonas hominis;* this flagellate was once mistaken for an amœba by Castellani (1905) who named it *Entamœba undulans.*

Karyamœbina falcata was found by Kofoid and Swezy (1924) in three individuals. Only trophozoites were observed. Its pseudopodia are formed abruptly, sometimes two or three at once, and the organism is very active. The nucleus contains an eccentric karyosome and one, two or three large crescentic chromatin masses on the nuclear membrane. About twenty chromosomes appear during mitosis. This species has not been observed by any other investigators and must be considered doubtful until further data are available.

Endamœba dispar is the specific name given by Brumpt (1925, 1928) to an amœba that he believes is ordinarily confused with *Endamœba histolytica,* but that is distinguishable from the latter largely on physiological grounds. It is non-pathogenic and never ingests red blood cells in man or in culture, although it very rarely does so in kittens. The cysts are not distinguishable from those of *E. histolytica.* It will be difficult for Brumpt to satisfy protozoölogists of the existence of this species.

X. *Coprozoic Amœbæ*

Protozoa that live in fecal material are said to be coprozoic. They are free-living species which either find their way into the feces after passage from the body, or else are swallowed in the cyst stage, pass through the alimentary canal unchanged and hatch after their escape from the body. Coprozoic Protozoa are of particular importance because they may be confused with parasitic species, especially

when stools are kept moist and warm for some hours before examination.

Hartmannella hyalina has frequently been cultivated from human feces (Musgrave and Clegg, 1904). It possesses a single contractile vacuole; and a cyst stage, but not a flagellated stage, occurs in its life-cycle. *Dimastigamœba gruberi* is another common coprozoic species that possesses a contractile vacuole; both cyst stage and a flagellate stage occur in its life-cycle (Wilson, 1916). *Sappinia diploidea* occurs commonly in the feces of lower animals and more rarely in those of man. It possesses a contractile vacuole and two nuclei. A cyst stage has been described consisting of two individuals within a single wall. The shelled rhizopod, *Chlamydophrys stercorea,* was reported by Schaudinn (1903) from human feces, but he probably confused this form with one of the parasitic amœbæ. *C. stercorea,* however, occurs commonly in the feces of frogs, pigs and horses. The trophozoite (Figure 3b) is surrounded by an egg-shaped, transparent shell about 15 μ in length, through a pore in one end of which pseudopodia are extruded. Cysts occur in its life-cycle.

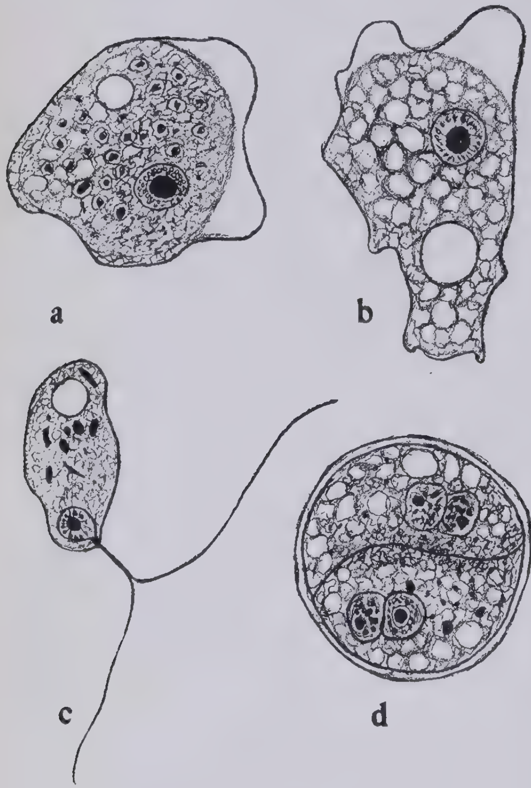


FIG. 14.—Coprozoic amœbæ.
a. *Hartmannella hyalina.* Trophozoite.
b. *Dimastigamœba gruberi.* Amœboid form.
c. *Dimastigamœba gruberi.* Flagellate form.
d. *Sappinia diploidea.* Trophozoite. (All after Dobell and O'Connor. x 2000)

XI. *Methods of Obtaining and Preparing Amœbæ for Study*

I. COLLECTION OF MATERIAL

Fecal samples should be collected in clean, dry containers that are free from antiseptics. If possible they should be deposited directly into a container and not in a water-closet first. They should also be kept free from urine. The sigmoidoscope has been used by Paulson and Andrews (1927) for obtaining material directly from the intestine but this is not necessary under ordinary conditions.

Whenever possible the entire stool should be obtained. If this cannot be accomplished, then samples from several parts of the stool should be selected. The paraffin pasteboard containers commonly used for transporting ice-cream are well adapted for the collection of samples. Small pill boxes may be used for smaller samples and these may be sent by mail in ordinary cylindrical mailing cases. Feces that are naturally passed are more useful than those obtained after a purgative. If a cathartic is necessary, a saline purge is preferable to oil, since the oil drops in the feces are confusing.

Fecal samples should be examined as soon as possible after they are passed, since the active trophozoites become quiescent when the material becomes cold and soon die. It is advisable to keep the feces warm either in a vacuum bottle or in a thermopack. A stool in a pasteboard container, if placed in a thermopack with several containers filled with water at body temperature, will remain warm for a considerable period. A warm stage is not necessary for a rapid examination. The cysts of intestinal amœbæ live for many days in fecal material, hence they may be looked for in older stools. Active amœbæ that appear in old stools are coprozoic species and not former inhabitants of the human intestine.

2. PREPARATION OF SMEARS

Living specimens. The amœbæ of man can be identified usually in the living condition. It is important, however, that fresh material be used for this purpose and that it be prepared in such a way as not to destroy the organisms. Amœbæ that are moving about, and cysts can be detected with a 16 mm. objective and a number 10 ocular. After the organism is found the species can be determined with the 4 mm. objective. A simple method of preparing a smear is to take very small samples from various parts of the stool and emulsify them with a toothpick on a slide in 0.7 per cent saline solution. A number

1 cover-glass can be added and the material spread out beneath it until a very thin layer is formed. A frequent mistake is the use of too much material, thus forming such a thick smear that the protozoa cannot be distinguished. Organisms are often to be found in the mucus on the outside of formed stools, hence samples from both outside and inside should be made. The smear, of course, should never be allowed to dry since this quickly kills the amœbæ and modifies their shape so that they cannot be identified. The addition of neutral red or eosin 1 : 10,000 may aid in diagnosis since the débris is stained but not the cysts. The trophozoites are not killed by these dyes.

Dead specimens killed with iodine. The identification of cysts of amœbæ depends largely on the number and character of the nuclei they contain. Nuclei are often difficult to observe in living specimens, hence it is customary to add to the smear an iodine solution. A saturated solution of iodine in 5 per cent aqueous potassium iodide should be used. The amœbæ are killed by this solution and the number and much of the structure of the nuclei can then be determined; the presence or absence of glycogen and its mass and shape can also be observed.

Dead specimens killed with Schaudinn's solution and stained with iron-hæmatoxylin. In some cases it is impossible to determine with certainty the species present in anything but a fixed and stained smear. The best method of making such preparations is to spread a thin moist film on a slide or cover-glass, drop it before it has a chance to dry into Schaudinn's fixing solution and then stain it in iron-hæmatoxylin. The following is a short outline of the steps in the preparation and staining of smears by the Heidenhain iron-hæmatoxylin process.

1. A small bit of feces is smeared on a cover-glass with a glass rod so as to form a thin moist film.
2. Drop immediately face downward into warm (heated only to point where steam rises) Schaudinn's fluid which is composed of the following:

   Distilled water saturated with mercuric chloride (Hg_2Cl_2) . 65 pts
   95 per cent alcohol .... 33 pts.
   Glacial acetic acid .... 2 to 5 pts.

   The film will float on the surface at first. After a few seconds it can be completely immersed and left in the fluid for from 10 to 20 minutes.
3. Wash and harden by the following steps:

   a. Wash in 50 per cent alcohol for a few minutes.
   b. Transfer to 70 per cent to which has been added a few drops

of alcoholic iodine solution (to remove sublimate) for at least 10 minutes.
   c. Harden in 95 per cent alcohol. When speed is essential this hardening may be shortened to a few minutes, but it is best to leave the film in the alcohol for an hour and even a few days does not injure it.
   d. Hydrate by successive immersions for a few minutes in 70 per cent and 50 per cent alcohol and distilled water.
4. Mordant by placing in a 2 per cent aqueous iron alum solution (ammonium-ferric sulphate) 30 minutes or longer (over night answers as well). While 30 minutes will suffice it is best to mordant for at least 2 hours.
5. Wash in distilled water for a few seconds.
6. Stain in 0.5 per cent aqueous hæmatoxylin solution. This should be made up several weeks previous to its use and allowed to "ripen." Several hours is sufficient for staining, but a longer time, viz., over night, is better.
7. Wash in distilled water.
8. Differentiate in 1-2 per cent aqueous iron-alum solution. This is by far the most difficult part of the process and can be done accurately only after practice. The overstained films are placed in the iron-alum solution and at intervals taken out, rinsed in distilled water and examined under the microscope. As each film is destained enough, it is washed in distilled water and then placed in running tap water for at least 20 minutes. It is often an advantage to start the differentiation with 2 per cent iron-alum solution, and as the films become destained to dilute the solution to about 0.5 per cent so that the end point is reached more slowly.
9. Wash in distilled water, as noted in (8).
10. Dehydrate by immersing successively for about five minutes each in 50 per cent, 70 per cent, 95 per cent and absolute alcohol (2 changes).
11. Clear by immersing in two changes of xylol (5 minutes each).
12. Mount by lowering the smear face-downward over a drop of Canada balsam on a slide and pressing it down gently.

3. CONCENTRATION METHODS

Often the cysts of amœbæ are present in fecal material in such small numbers that they cannot be found in smears without undue effort. To obviate this difficulty concentration methods have been perfected. Some of these methods are so complicated that they are of use only to professional protozoölogists. A simple method of washing and sedimentation, however, that is valuable for concentrating cysts may be described here. Fecal material is thoroughly stirred up in water and strained through two layers of cheese-cloth into a tall cylindrical graduate containing about two liters of water.

This is allowed to settle for a few hours and then some of the material at the bottom is removed with a long pipette and smears made. In some cases it is desirable to repeat this process several times.

XII. *Methods of Cultivating Amœbæ*

1. FREE-LIVING AND COPROZOIC AMŒBÆ

These are easily cultivated on a medium of Musgrave and Clegg (1904) which consists of

Agar	20.0 grams
Sodium Chloride	0.3-0.5 grams
Extract of beef	0.3-0.5 grams
Distilled water	1000 c.c.

This is rendered 1 per cent alkaline and made up in the same way as nutrient agar. It is poured into Petrie dishes and when congealed the material containing amœbæ is spread on the surface; the cultures must be kept moist and at a temperature of 20° C. to 25° C.

2. ENTOZOIC AMŒBÆ

Cutler (1918) appears to have been the first to cultivate an endamœba although no one has succeeded in repeating his work. An endamœba from the turtle, *E. barreti,* was cultivated by Barret and Smith (1924). Their medium consisted of 0.5 per cent sodium chloride solution, nine parts, and human blood serum, one part, and was kept at either room temperature or at 10° C. to 15° C.

A medium devised by Boeck and Drbohlav (1925) for the cultivation of *Endamœba histolytica* has been found to be very successful. This is known as the L.E.S. medium, inasmuch as it is made up of Locke's solution, egg, and human blood serum. The L.E.S. medium is prepared as follows:

"1. Four eggs were washed, brushed with alcohol and broken into a sterile flask containing glass beads. Fifty (50) c.c. of Locke's physiological solution are then added and the mixture broken up by shaking.

2. Test tubes are then filled with a sufficient quantity to produce slants from about 1 to 1½ inches in length upon coagulation by heat.

3. These tubes are now slanted in an inspissator and heated (70° C.) until the egg mixture has solidified. They are then transferred

to the autoclave and sterilized for 20 minutes at 15 pounds of pressure.

4. The tubes are now covered to a depth of 1 cm. above the egg slant with a mixture composed of 8 parts of sterile Locke's solution and 1 part of sterile inactivated human blood serum. They are then incubated to determine sterility.
5. The Locke solution is made up as follows:

Distilled water	1000 c.c.
NaCl	9.0 grams
CaCl	0.2 grams
KCl	0.4 grams
$NaHCO_3$	2.2 grams
Glucose	2.5 grams

The solution is sterilized, either in the Arnold or the autoclave, according to the ordinary methods." (Boeck and Drbohlav, 1925).

A second medium devised by Boeck and Drbohlav is the L.E.A. mixture, which differs from the L.E.S. medium by the substitution of a 1 per cent solution of crystallized egg albumin for the human serum. The work of Boeck and Drbohlav was first confirmed by Andrews (1925) and later by many other investigators.

A number of modifications and simplifications of these media have been reported. The most simple are those of Craig (1926). His Locke-Serum medium is made up as follows:

Sodium chloride	9.00 grams
Calcium chloride	0.24 grams
Potassium chloride	0.42 grams
Sodium bicarbonate	0.20 grams
Dextrose	2.50 grams
Distilled water	1000 c.c.

This solution is filtered, autoclaved at fifteen pounds pressure for fifteen minutes and allowed to cool. There is then added one part of inactivated human, horse or rabbit serum to each seven parts of the Locke solution used. After adding the blood serum the mixture is thoroughly shaken and filtered through a Mandler or Berkefeld filter. Later (Craig, 1926) two simpler media were devised; the Ringer-Serum medium is prepared by combining seven parts of a modified Ringer solution and one part of an inactivated human blood serum. The Ringer solution has the following formula:

Sodium chloride	8.0 grams
Calcium chloride	0.20 grams
Potassium chloride	0.20 grams
Distilled water	1000 c.c.

Craig's Normal-Salt-Serum medium is the most simple of all but has given this investigator good results. This medium is prepared by adding one part of inactivated human blood serum to seven parts of normal salt solution (0.85). The salt solution is autoclaved at fifteen pounds pressure for fifteen minutes before adding the serum, and the mixture is filtered, tubed, and tested for sterility in the same manner as the Locke-Serum and Ringer-Serum media. These results demonstrate that sodium chloride is the only constituent necessary besides blood serum for the continued cultivation of *Endamœba histolytica*. Much has been learned regarding the life-cycle of *E. histolytica* by means of artificial cultures as may easily be judged from the investigations of Yorke and Adams (1926a, 1926b, 1927), Dobell and Laidlaw (1926) and Dobell (1927). Craig and St. John (1927) have shown that this method may even be used to determine the presence of *E. histolytica* in stools and that a larger percentage of positives may be determined in this way than by the smear method. Dobell (1927) also states that "A culture frequently supplies a more accurate test of the presence of amœbæ than a microscopic examination." It remains to be proved that this method can be employed successfully under field conditions.

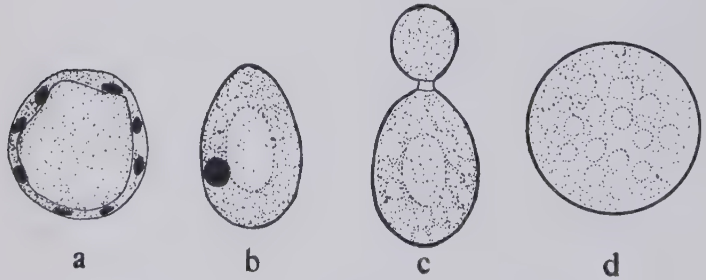


FIG. 15.—Vegetable organisms in human feces.
a. *Blastocystis hominis.*
b. Intestinal yeast.
c. Intestinal yeast, budding.
d. Intestinal mold. (All after Kofoid, Kornhauser and Swezy. x 2800)

XIII. *Pseudoparasites in Human Feces*

Besides coprozoic PROTOZOA, various objects in fecal material, such as vegetable organisms, human intestinal cells and mechanical artefacts may be mistaken for entozoic amœbæ. Various types of vegetable organisms resemble amœbic cysts; the most common of these are *Blastocystis hominis*, intestinal yeasts and fecal molds

Table I

DIFFERENTIAL DIAGNOSIS OF HUMAN INTESTINAL AMŒBÆ

	Stage and Condition	*Endamœba histolytica*	*Endamœba coli*	*Endolimax nana*	*Iodamœba williamsi*
Diameter	Trophozoite living	Usually 20 μ to 30 μ	Usually 20 μ to 30 μ	Usually 6 μ to 20 μ	Usually 9 μ to 13 μ
Locomotion	Trophozoite living	Active	Sluggish	Sluggish	Sluggish
Pseudopodia	Trophozoite living	Blade-like, hyaline, explosive	Blunt, slowly formed	Blunt, slow, several	Blunt, slowly formed
Cytoplasm	Trophozoite living	Ectoplasm sharply differentiated	Ectoplasm not sharply differentiated	Ectoplasm not sharply differentiated	Ectoplasm not sharply differentiated
Nucleus	Trophozoite living	Faint or invisible	Visible	Faintly visible	Sometimes visible
Inclusions	Trophozoite living	Red blood cells, no bacteria	Bacteria and débris	Bacteria and débris	Bacteria and débris
Nucleus	Trophozoite, stained with iron-hæmatoxylin	4 μ to 7 μ; karyosome small, central; thin peripheral chromatin; membrane thin	4 μ to 8 μ; karyosome large, eccentric;; heavy peripheral chromatin; membrane thick	1 μ to 3 μ; one large or several connected karyosomes; no peripheral chromatin	2 μ to 3 μ; one large central karyosome surrounded by refractile granules
Diameter	Cyst, living	5 μ to 20 μ	10 μ to 30μ	8 μ to 10 μ by 7 μ to 8 μ	8 μ to 12 μ
Shape	Cyst, living	Spheroidal	Spheroidal	Ellipsoidal	Spheroidal or irregular
Nucleus	Cyst, living	Faint or invisible	Visible	Usually invisible	Faint or invisible
Glycogen	Cyst, stained with iodine	Present in young cysts; stains dark mahogany brown	Present in young cysts; usually larger than in *E. histolytica*	Sometimes present in young cysts	Almost always present and large
Nuclei	Cyst, stained with iron-hæmatoxylin	4, structure as in trophozoite	8, structure as in trophozoite	4, structure as in trophozoite	1, refractile granules at one side
Chromatoid bodies	Cyst, stained with iron-hæmatoxylin	Often present; rod-like with rounded ends	Sometimes present; like splinters of glass	None	None

(Figure 15). Dysenteric stools contain many bodies that may be mistaken for PROTOZOA, especially macrophage cells, and polymorphonuclear leucocytes which may ingest red blood cells. Beginners often mistake such objects as air bubbles and oil globules for cysts of amœbæ, but one soon learns to recognize these as mechanical artefacts.

XIV. *Differential Diagnosis of Human Amœbæ*

Table I presents the principal features of the four common amœbæ that live in man in such a manner that they may easily be compared. The criteria of importance in identifying living trophozoites are size, speed of locomotion, character and method of formation of the pseudopodia, differentiation between ectoplasm and endoplasm, visibility of the nucleus and character of the inclusions. In trophozoites stained with iron-hæmatoxylin the nuclear structures are clearly exhibited; these are size, mass, number and location of the karyosomes, the presence or absence and thickness of the peripheral chromatin, if present, and the thickness of the nuclear membrane. Living cysts may be distinguished by their size, shape and visibility of the nuclei. Cysts stained with iodine show the number of nuclei and the presence or absence and characteristics of glycogen bodies, if present. Nuclear number and structure and chromatoid bodies are revealed in cysts stained with iron-hæmatoxylin.

CHAPTER IV

AMŒBÆ OF LOWER ANIMALS

I. *Amœbæ of Monkeys*

At least eleven species of amœbæ belonging to three genera have been described from monkeys. One of these, named *Endamœba nuttalli* by Castellani in 1908, resembles *Endamœba histolytica* so closely, both in the trophozoite and cyst stages, that many authorities believe them to belong to the same species. Another, named *Endamœba pitheci* by Prowazek in 1912, is structurally indistinguishable from *Endamœba coli* both in the trophozoite and cyst stages. It seems probable that seven of the other species named from monkeys belong to one or the other of these two species. Brug in 1921 described a species of iodamœba from a monkey to which the name *Iodamœba kueneni* was given; this species may be the same as *Iodamœba williamsi* in man. The same investigator (Brug, 1923) described an endolimax from a monkey for which he proposed the name *Endolimax cynomolgi*; this may be the same species as *Endolimax nana* in man. Amœbæ belonging to these various species have been reported from the gorilla, chimpanzee, orang-utan, baboon and a number of other species of monkeys from both the Old World and the New World. Most of the monkeys in which the amœbæ have been found were in captivity and it is possible that they may have become infected with human amœbæ. The histolytica-like amœba may produce in monkeys both amœbic dysentery and amœbic liver abscesses. As already noted, there is evidence that *E. histolytica, E. coli* and other species of amœbæ can be transferred from man to monkeys successfully (Kessel, 1924).

II. *Amœbæ of Domesticated Mammals and Birds*

Amœbæ have been found in practically all of the domesticated mammals and birds. Many of these have been considered specifically different from those described from man and have been given specific names. How many of these are actually distinct species remains to be determined. None of these species seem to be severely pathogenic but live the lives of harmless commensals in the mouth or intestine.

1. FOOD ANIMALS

Amœbæ were described from the stomach of cattle by Liebetanz (1905) and given the name *Endamœba bovis*. Nieschulz (1922) reported the finding of cysts in the feces of cattle but whether these belong to the same species or not is unknown. An amœba called *Endamœba intestinalis* was reported by Gedoelst (1911) from horses; this species has been found by Fantham (1920) in the colon and cecum of horses in South Africa as well as a second species, *Endamœba equi* (Fantham, 1921), which ingests red blood cells and is presumably pathogenic. Pigs harbor not only endamœbæ but also iodamœbæ. Amœbæ were discovered in the intestinal ulcers of pigs by Theobald Smith (1910); they were probably of the species named *Endamœba polecki* by Prowazek (1912). A second species of endamœba, *E. debliecki*, which is smaller than the first, has been described by Nieschulz (1924). An iodamœba was described by O'Connor (1920) from pigs in the Ellice Islands; to this the name *I. suis* was given. Several investigators have since found iodamœbæ in pigs in various parts of the world, including the United States (Hegner and Taliaferro, 1924). It is still to be determined whether the iodamœbæ of man and the pig belong to the same species. An extensive report on the protozoa of pigs has recently been published by Kessel (1928). An amœba named *Endamœba ovis* has been reported from sheep (Swellengrebel, 1914) and another, named *Endamœba capræ*, from goats (Fantham, 1923). Endamœbæ have been described from the mouth of the horse as *Endamœba gingivalis* var. *equi* (Nieschulz, 1924).

2. PETS

Household pets, such as cats and dogs, are frequently infected with amœbæ. Spontaneous amœbic dysentery in both dogs and cats has been reported by a number of investigators. The amœba concerned is probably *E. histolytica*. As noted above, experimental infections may be set up in both of these animals with *E. histolytica* from man. An amœba indistinguishable from *E. gingivalis* has also been reported from the dog (Goodrich and Moseley, 1916).

3. LABORATORY ANIMALS

Many rodents are susceptible to amœbic infections. An amœba of the *Endamœba coli* type, named *E. cuniculi*, has been found in rabbits (Brug, 1918). Guinea-pigs harbor a similar form named

E. cobayæ (Walker, 1908). Cysts containing both four nuclei (Leger, 1918) and eight nuclei (Holmes, 1923) have been found in guinea-pigs. The amœbæ of rats and mice have been studied more carefully than those of other rodents. The commonest species, known as *E. muris,* is of the *E. coli* type, but amœbæ resembling *E. histolytica* have also been reported (Brug, 1919; Chiang, 1925). Species of the genus *Councilmania* have also been reported from rats and mice (Kofoid, Swezy and Kessel, 1924). An endolimax indistinguishable from *E. nana* was reported by Chiang and given the name *E. ratti* because this investigator was unable to infect rats with *E. nana* from man.

4. BIRDS

Amœbæ have been described from the intestine of grouse, fowls and ducks. A species named *Endamœba lagopodis,* whose cysts contain four nuclei, was reported from grouse by Fantham (1910). Amœbæ with eight-nucleate cysts have been recovered from fowls (Hartmann, 1913; Tyzzer, 1920) and a species named *E. anatis* has been described from ducks in South Africa (Fantham, 1924). The cecum of the fowl is also the habitat of an endolimax. Tyzzer (1920) gave this form the name *Pygolimax gregariniformis,* but it no doubt belongs to the genus *Endolimax* (Hegner, 1926).

III. *Amœbæ of Other Animals*

Many species of amœbæ have been described from other lower animals; a few of these, of particular interest because of the ease with which they may be obtained or of the nature of their hosts, may be mentioned here. *Endamœba ranarum,* which occurs in the intestine of the frog, is indistinguishable morphologically from *E. histolytica,* but attempts to infect tadpoles with histolytica cysts have failed (Dobell, 1918). As noted in Chapter III (page 66), the first endamœba of a cold-blooded animal to be cultivated was *E. barreti* which occurs in the turtle (Barret and Smith, 1923; Taliaferro and Holmes, 1923). Amœbæ have been reported from the intestine of other reptiles, for example, snakes and lizards, and from the newt and a species has been described from the intestine of fish. Many invertebrates also serve as hosts of endamœbæ. The vagina of the horse-leech is the habitat of *Endamœba aulastomi.* Various insects are infected, for example the larvæ of the crane fly by *E. minchini* (MacKinnon, 1914), the water-bug, *Belostoma,* by *E. belostomæ,* and the honey-bee by *E. apis.*

The amœba of the cockroach, *E. blattæ,* which is the type species of the genus *Endamœba* (Leidy, 1879) has been studied more than any other amœba that occurs in invertebrates. The trophozoite (Figure 16 a, b) is very large and may reach a diameter of 120 μ, being usually about 50 μ. The nucleus is large, often lemon-shaped, and possesses a very thick membrane. There is no central karyosome, the chromatin material being arranged in a broad peripheral zone of granules (Figure 16 d). Trophozoites with many nuclei occur. Cysts

FIG. 16.—*Endamœba blattæ.*

a. Trophozoite, living.
b. Trophozoite, living, containing many yeast cells and a living flagellate, *Lophomonas blattarum.*
c. Cyst, stained, containing thirty-eight nuclei.
d. Nucleus of trophozoite, stained. (All from drawings by Miss Catherine Lucas. x 650)

(Figure 16 c) contain from eight to over thirty nuclei (Thomson and Lucas, 1926). A rather complete life-cycle of this species has been furnished by Mercier (1910) but has not yet been confirmed.

A number of species of the genus *Endolimax* have also been reported from lower animals. One of these occurs in the frog. Another, *E. reynoldsi,* has been described from a lizard (McFall, 1926). *Endolimax blattæ* is a species that has recently been reported from the cockroach (Lucas, 1927). Other species occur in the flea and the leech.

A number of species of the genus *Vahlkampfia* have been found in lower animals. For example, Hogue (1921) has described as *V. patuxent* (Figure 17 a), a species that occurs in the stomach of

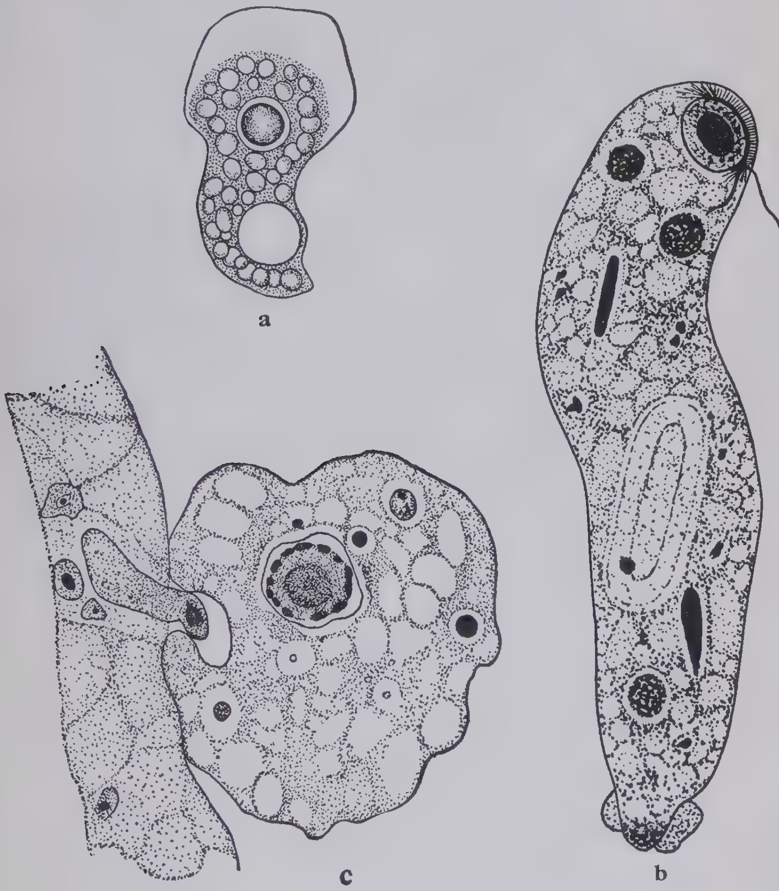


FIG. 17.—Amœbæ of lower animals.
a. *Vahlkampfia*, living specimen. (From Wenyon, after Vahlkampf)
b. *Mastigina hylæ*, from the intestine of the tadpole. (After Becker)
c. *Amœba hydroxena* ingesting an epithelial cell of *Hydra*. (After Root)

the oyster. No flagellate stage could be found in the life-cycle of this form. An interesting amœba, known as *Mastigina hylæ* (Figure 17 b) occurs in tadpoles; the nucleus is near the anterior end and a short, inactive flagellum extends out from a blepharoplast located

on the nuclear membrane (Becker, 1925). Even *Hydra* is parasitized by an amœba (Figure 17 c). This species, *A. hydroxena* (Entz, 1912), is very large, ranging from 100 μ to 368 μ in diameter, has one or several contractile vacuoles and is ectozoic in habit, feeding largely on the epithelial cells of its hydroid host. (See Reynolds and Looper, 1928.)

CHAPTER V

INTRODUCTION TO THE MASTIGOPHORA

I. *Classification*

Although the presence of one or more flagella in the so-called adult stage is the most conspicuous characteristic of the MASTIGOPHORA, flagella are not always present, and certain SARCODINA have a flagellated stage in their life-cycle. With these reservations the statement that MASTIGOPHORA are PROTOZOA with flagella is correct. There are two primary types of MASTIGOPHORA, those belonging to the subclass PHYTOMASTIGINA being plant-like, and those in the subclass ZOÖMASTIGINA being animal-like. Comparatively few of the PHYTOMASTIGINA are parasitic, whereas large numbers of parasites occur among the ZOÖMASTIGINA. In the follownig classification certain families are listed under the order PROTOMONADINA because most of the flagellates parasitic in man and animals belong to this order.

Class MASTIGOPHORA. PROTOZOA with flagella.

Subclass 1. PHYTOMASTIGINA. Plant-like flagellates.

Order 1. CHRYSOMONADINA. Small, simple, with one or two flagella. Examples: *Chrysamœba radians, Chromulina flavicans.*

Order 2. CRYPTOMONADINA. Small, oval, with rigid periplast and two flagella. Examples: *Cryptomonas ovata, Chilomonas paramœcium.*

Order 3. DINOFLAGELLATA. Mostly marine, with two flagella, one in a groove. Examples: *Gymnodinium roseum, Oodinium parasiticum.*

Order 4. EUGLENOIDINA. One or two (rarely three) flagella; complex vacuole system. Examples: *Euglena viridis. Copromonas subtilis. Euglenamorpha hegneri.*

Order 5. PHYTOMONADINA. Mostly with thickened cuticle forming a lorica, with two flagella. Examples: *Volvox globator, Hæmatococcus pluvialis.*

Subclass 2. ZOÖMASTIGINA. Animal-like flagellates.

Order 1. PROTOMONADINA. One nucleus, few flagella.

Family 1. MONADIDÆ. Examples: *Oikomonas termo, Heteromita uncinata.*

Family 2. TRYPANOSOMIDÆ. Examples: *Leptomonas ctenocephali, Crithidia gerridis, Trypanosoma gambiense.*

Family 3. BODONIDÆ. Examples: *Bodo caudatus, Rhynchomonas nasuta.*

Family 4. PROWAZEKELLIDÆ. Example: *Prowazekella lacertæ.*

Family 5. EMBADOMONADIDÆ. Example: *Embadomonas intestinalis.*

Family 6. CHILOMASTIGIDÆ. Example: *Chilomastix mesnili.*

Family 7. CERCOMONADIDÆ. Examples: *Cercomonas longicauda, Tricercomonas intestinalis.*

Family 8. CRYPTOBIIDÆ. Examples: *Cryptobia helicis, Trypanoplasma borreli.*

Family 9. TRICHOMONADIDÆ. Examples: *Trichomonas hominis, Polymastix melolonthæ.*

Family 10. DINENYMPHIDÆ. Examples: *Dinenympha gracilis.*

Order 2. HYPERMASTIGINA. One nucleus, many flagella. Examples: *Lophomonas blattarum, Trichonympha agilis.*

Order 3. DIPLOMONADINA. Two nuclei, body bilaterally symmetrical, flagella paired. Examples: *Giardia lamblia, Hexamita muris.*

Order 4. POLYMONADINA. More than two nuclei, many flagella. Examples: *Calonympha grassii, Stephanonympha silvestrini.*

II. *Euglena*

Euglena is a very common plant-like flagellate that occurs in bodies of fresh water in which they are sometimes so numerous that they produce a greenish tinge. The body has a definite shape as indicated in Figure 18, the peripheral layer of ectoplasm being modified into a firm but flexible cuticle on which there are longitudinal spiral markings. A single flagellum arises at the anterior end from a depression, the cytostome. The cytostome leads into a short gullet which connects with a vacuole-like reservoir into which a number of small contractile vacuoles discharge their contents from time to time. It is

supposed that excretory products are discharged from the body by way of the reservoir. Near the anterior end of the body is a reddish structure known as the stigma or eye-spot. A single nucleus lies near the center of the body. In the endoplasm are many chlorophyll-bearing bodies known as chromatophores; these give the animal its green color. Besides this other inclusions consist of paramylum which is carbohydrate in nature.

Euglena probably obtains its nutriment by all three of the most common methods. With the aid of chlorophyll, sunlight and carbon dioxide it is able to manufacture food in the form of paramylum; this is a plant-like method of nutrition known as holophytic. There is good evidence that euglena also absorbs nutriment, in the form of decomposed organic material, through the general body wall, and is thus saprophytic. Recent observations indicate that in some cases euglena may actually ingest bacteria through the cytostome; if this is correct, holozoic nutrition may be added to the other two types.

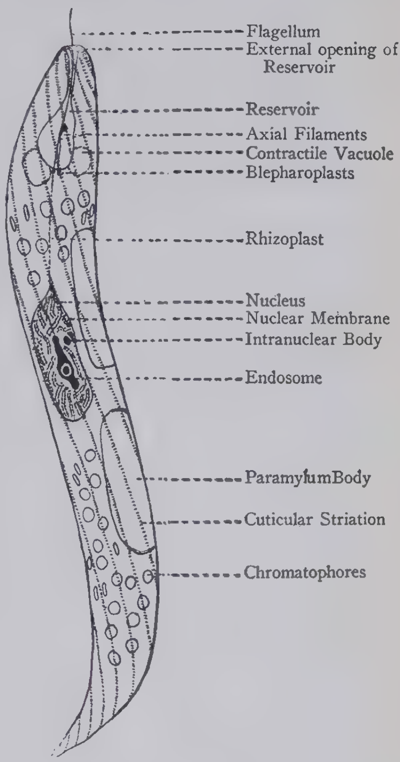


FIG. 18.—*Euglena spirogyra,* a plant-like flagellate (x 700). (After Ratcliffe)

Locomotion in euglena is effected by means of the flagellum, the organism swimming through the water in a spiral course. Euglena is also capable of movements, known as euglenoid movements, consisting of peristaltic waves, which pass over the animal from the anterior to the posterior end. Various external stimuli have effect on the movements of the organism, especially changes in the intensity and direction of the light.

Reproduction in euglena is principally by longitudinal division, although transverse division also occurs. Under certain conditions the

organisms may encyst, becoming spherical and secreting about themselves a thin cyst wall. They may emerge from the cyst without dividing or may undergo one or several divisions before the cysts hatch. Conjugation may possibly occur but has not yet been demonstrated with certainty.

III. *Parasitic Mastigophora in General*

1. PARASITIC PLANT-LIKE FLAGELLATES

Euglena viridis has been presented as a representative of a plant-like flagellate. This and many other species of the PHYTOMASTIGINA are free-living in habit. Many of the plant-like flagellates, however, are parasitic or coprozoic. Of these several of the euglenoidina and dinoflagellata are of particular interest. A species of euglenoidina, named by Wenrich (1923) *Euglenamorpha hegneri*, differs from other members of this order in the possession of three flagella (Hegner, 1923). This species occurs in the intestine of tadpoles in North America. A related species was discovered by Brumpt and Lavier (1924) in tadpoles in Brazil. A new genus, *Hegneria*, was proposed for this species, and the organism, which possesses seven flagella, named *Hegneria leptodactyli*. The genera *Euglenamorpha* and *Hegneria* were placed by Brumpt and Lavier in the family HEGNERELLIDÆ. Several species of the genus *Astasia* are parasitic, for example, *A. captiva* is endoparasitic in a flatworm and *A. mobilis* in the egg sacks and digestive tract of cyclops. It seems possible that the parasitic habit of such species as *Euglenamorpha hegneri* may have evolved as a result of the ingestion of free-living euglenoids by tadpoles and other aquatic animals.

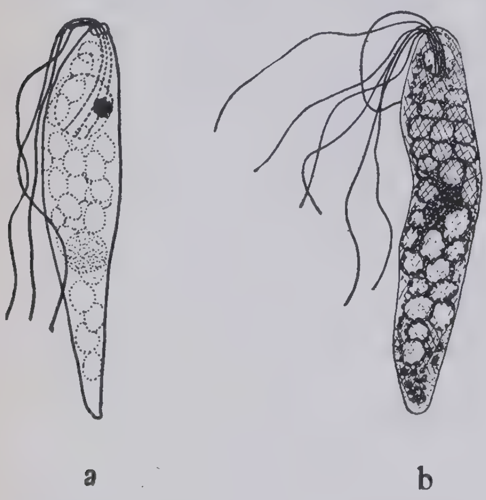


FIG. 19.—Parasitic EUGLENOIDINA from frog tadpoles. a. *Euglenamorpha hegneri* (x 1600). (After Hegner) b. *Hegneria leptodactyli* (x 1000). (After Brumpt and Lavier)

Large numbers of parasites occur among the dinoflagellates. The family BLASTODINIDÆ contains only parasitic species. Many types and degrees of parasitism are exhibited by members of this family (Chatton, 1920). Some are ectoparasitic, and others endoparasitic in tissues or cavities.

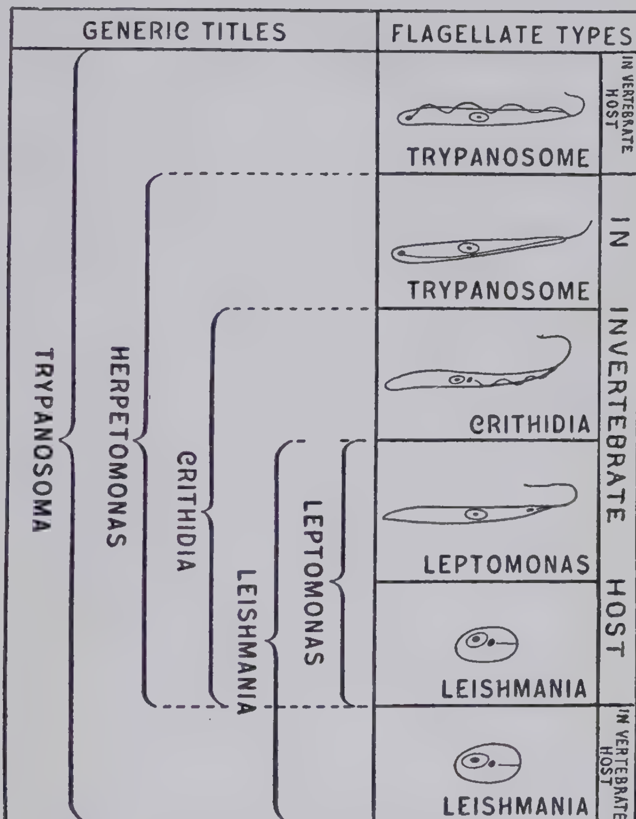


FIG. 20.—TRYPANOSOMIDÆ. Stages in the life-cycle of five genera in vertebrate and invertebrate hosts. (After Wenyon)

2. TRYPANOSOMIDÆ, EXCLUSIVE OF THE GENERA TRYPANOSOMA AND LEISHMANIA

The family TRYPANOSOMIDÆ contains a large number of hemoflagellates and allied forms. Those belonging to the genera *Trypano-*

soma and *Leishmania* are of particular importance to us since many of them are pathogenic to man and domesticated animals. These are treated in Chapter VI. The genera belonging to this family and some idea of the stages through which they pass and the hosts in which they live are indicated in Figure 20.

Members of the genus *Leptomonas* exist in the leishmania and leptomonas stages, which live only in invertebrate hosts, from one to another of which they are transmitted in the form of cysts that are passed in the feces.

FIG. 21.—Types of TRYPANOSOMIDÆ.
a. *Herpetomonas muscæ-domesticæ* (x 2500). (After Swezy)
b. *Leptomonas ctenocephali* (x 2000). (After Shortt)
c. *Phytomonas elmassiani* (x 3000). (After Holmes)
d. *Crithidia gerridis,* with divided blepharoplast (x 2140). (After Becker)

Members of the genus *Crithidia* exist in three forms, leishmania, leptomonas and crithidia; they are limited to invertebrate hosts and transmitted by means of cysts that are passed in the feces.

Members of the genus *Herpetomonas* exist in four stages, leishmania, leptomonas, crithidia and trypanosome; occur only in invertebrate hosts; and are transmitted by cysts passed in the feces.

Members of the genus *Leishmania* exist in two stages, leishmania and leptomonas, but occur in both vertebrate and invertebrate hosts, one stage in the life-cycle probably being passed in each; methods of transmission in this genus are not well known.

Members of the genus *Trypanosoma* pass through all of the stages illustrated and may occur in both vertebrate and invertebrate hosts, passing from invertebrate to vertebrate or from vertebrate to invertebrate.

Members of the genus *Phytomonas* resemble leptomonads, but live both in plants and in invertebrates, the latter being the transmitting agent.

Leptomonas. The leptomonads are the simplest of all the types of TRYPANOSOMIDÆ and from them the other genera seem to have evolved. *Leptomonas ctenocephali* (Figure 21b), a species that lives in the intestine and malpighian tubules of the flea, has been studied extensively. It occurs only in the invertebrate host and in the two stages, leptomonas and leishmania. The leptomonas form is slender, often curved, and up to 18 μ in length; all gradations exist between this and leishmania forms no more than 3 μ in diameter. There is a nucleus, an anterior flagellum and a parabasal body; the latter is referred to by most English protozoölogists as a kinetoplast and by the French as a centrosome. The organism multiplies by binary fission and is transmitted in the leishmania stage which arises in the hind gut and is cyst-like. Laveran and Franchini (1913, and later papers) claim to have infected vertebrates with this and other flagellates from the intestine of insects. A number of investigators have attempted to repeat these experiments without success (Hoare, 1921; Glaser, 1922; Shortt, 1923; and Becker, 1923). These flagellates may be cultivated in the N. N. N. medium (Novy-MacNeal-Nicolle, see page 97). Tyzzer and Walker (1919) compared the growth of *Leptomonas ctenocephali* and *Leishmania donovani* in culture media and note various differences which indicate that these two forms do not belong to a single species.

Crithidia. The members of this genus are also exclusively parasites of invertebrates, especially insects; but crithidia that occur in certain insects may simply be a stage in the development of a trypanosome. The crithidia stage is long and slender; the blepharoplast is near and in front of the nucleus and an undulating membrane, along the edge of which the flagellum is attached, extends from the blepharoplast to the anterior end. *Crithidia gerridis* (Figure 21d) occurs in a large percentage of North American water striders, *Gerris remigis* (Becker, 1923). The organisms occur from the first stomach to the rectum; in the latter cysts and encysting forms may be found; multiplication is by binary fission. The detailed life history of another species, *Crithidia euryophthalmi,* has been worked out by McCulloch (1917, 1918). This species lives in the intestine of

Europhthalmus convivus, an hemipterous insect that feeds on sap. Infection is brought about by the contamination of food with infected feces.

Herpetomonas. Herpetomonas muscæ-domesticæ (Figure 21a) is a representative of the genus *Herpetomonas* that may be obtained from the intestine of house-flies. It differs from leptomonads in the presence of a trypanosome stage in the life-cycle. Transmission is brought about by the contamination of food by infected fecal material. Herpetomonads from various species of flies have been given different specific names, but the work of Becker (1923), who found that flagellates from any one of six species of naturally infected flies were capable of producing an infection in the other five species when inoculated per os, indicates that the forms occurring in these different species of flies are actually all one species.

Phytomonas. The phytomonads are usually referred in the literature to the genus *Herpetomonas,* but their presence in both plants and insects makes it worth while to place them in a separate genus. They occur in leptomonas and leishmania stages. They were discovered first in the latex of euphorbias (La Font, 1909) and later in milkweeds (Migone, 1916). *Phytomonas elmassiani* (Figure 21c) has been found in many of the milkweeds of Maryland (Holmes, 1925a) and as far north as the northern boundary of New Jersey and in Honduras (Hegner) and Haiti (Kunkel). It does not parasitize the entire plant but lives as an intracellular, but not an intracytoplasmic, parasite in certain latex cells. The hemipterous insect, *Oncopeltus fasciatus,* is the vector; the flagellates occur in the dorsal and anterior lobes of the trilobed salivary glands of this bug (Holmes, 1925b, 1925c). Strong (1924) believes he has demonstrated that certain lizards become infected from insects in which plant flagellates occur and that specimens from the lizard are capable of producing lesions following subcutaneous inoculation in the monkey. This work needs confirmation.

3. PARASITIC ANIMAL-LIKE FLAGELLATES

All of the orders of the ZOÖMASTIGINA and all of the families of the PROTOMONADINA listed above contain parasitic species. A number of genera are reserved for more detailed consideration in Chapter VII, and only a few of the more interesting species are described here.

Histomonas meleagris. This is an organism about which much has been written. It was described as *Amœba meleagris* by Theobald

Smith in 1895, but recent investigations indicate that it is a flagellate with one to four flagella that lives in the intestine of fowls and is able to invade the tissues (Tyzzer, 1924; Drbohlav, 1924). It is a pathogenic species and gives rise to what is known as blackhead of turkeys.

Costia necatrix. This is a flagellate parasitic on the skin of fish. It possesses two flagella and a contractile vacuole. Longitudinal division takes place and a cyst stage occurs in the life-cycle. Young fish, to which the flagellates attach themselves by their flagella, may be killed by the attack.

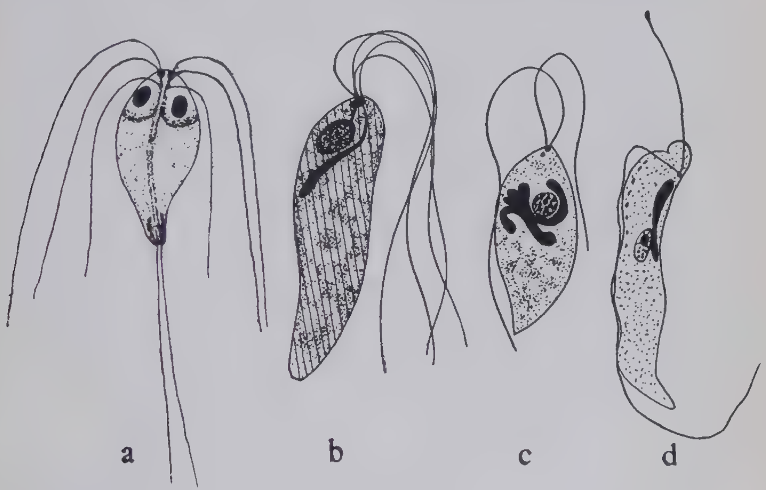


FIG. 22.—Parasitic animal-like flagellates belonging to four common genera.
a. *Hexamita salmonis* (x 2400). (After Davis)
b. *Polymastix bufonis* (x 2066). (After Swezy)
c. *Prowazekella lacertæ* (x 2066). (After Swezy)
d. *Cryptobia congeri* (x 2000). (From Swezy, after Martin)

Prowazekella lacertæ. Flagellates of this species (Figure 22c) live in the intestine of lizards. There are two flagella, one directed forwards and the other backwards. The nucleus lies near the anterior end of the body, and partly surrounding it is a conspicuous parabasal body.

Cryptobia helicis. Leidy discovered this flagellate in 1846 in the sexual organs of various species of snails of the genus *Helix*. There are two flagella (Figure 22d), one anterior, the other arising at the anterior end but running back along the body to which it is attached. There are two blepharoplasts from which the flagella arise, a parabasal body and a nucleus.

Trypanoplasma borreli. The blood of fish is sometimes parasitized by this and other species of flagellates belonging to the same genus. They are transmitted from one fish to another by leeches. The structure of this species is similar to that of *Cryptobia helicis* except that the posteriorly directed flagellum is attached to the edge of an undulating membrane.

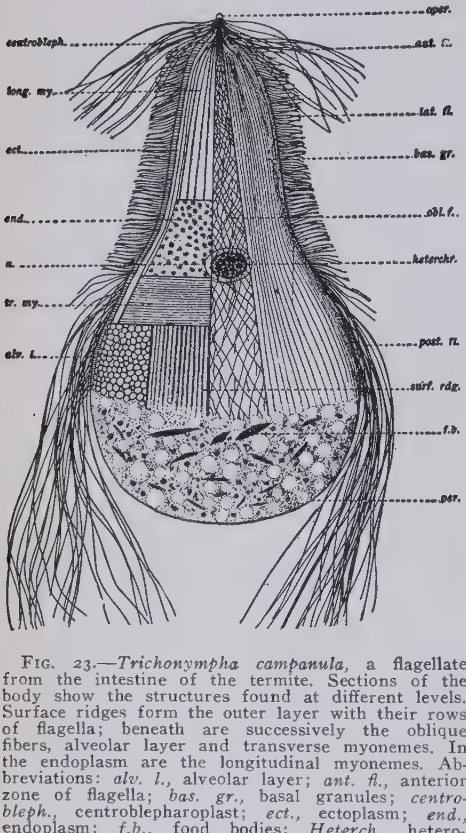


FIG. 23.—*Trichonympha campanula,* a flagellate from the intestine of the termite. Sections of the body show the structures found at different levels. Surface ridges form the outer layer with their rows of flagella; beneath are successively the oblique fibers, alveolar layer and transverse myonemes. In the endoplasm are the longitudinal myonemes. Abbreviations: *alv. l.,* alveolar layer; *ant. fl.,* anterior zone of flagella; *bas. gr.,* basal granules; *centrobleph.,* centroblepharoplast; *ect.,* ectoplasm; *end.,* endoplasm; *f.b.,* food bodies; *Heterch.,* heterochromosome; *lat. fl.,* lateral zone of flagella; *long. my.,* longitudinal myonemes; *n.,* nucleus; *obl. f.,* oblique fibers; *oper.,* operculum; *per.,* periplast; *post. fl.,* posterior zone of flagella; *surf. rdg.,* surface ridges; *tr. my.,* transverse myonemes (x 300). (After Kofoid and Swezy)

Polymastix melolonthæ. The intestine of insect larvæ is the habitat of this species. Two pairs of flagella arise at the anterior end. (Figure 22b.) A poorly developed axostyle is present. The surface of the body exhibits more or less longitudinal folds or ridges, resembling in this respect certain species of the HYPERMASTIGINA that occur in the intestine of the cockroach.

Lophomonas blattarum. This flagellate (Order HYPERMASTIGINA) occurs in the intestine of the cockroach. It possesses many flagella arranged in two tufts at the anterior end. There is a parabasal body associated with the nucleus, and an axostyle.

Hexamita muris. This species (Figure 22a and Figure 42) is a representative of the order DIPLOMONADINA. It occurs in the intestine of rats and mice, and possesses two nuclei, two groups of three anterior flagella and two posterior flagella which arise from axonemes. Cysts

are formed in which nuclear division occurs. Transmission is no doubt by the ingestion of these cysts in contaminated food.

4. INTESTINAL FLAGELLATES OF TERMITES

Flagellate inhabitants of the intestine of termites are of special interest because of the number of species, the number of individuals in a single termite, their complexity, the large number of flagella possessed by many of them and the symbiotic relations between some of them and their hosts. Species from at least eleven families and forty genera of flagellates have been reported from termites (Cleveland, 1923). A species that well illustrates the enormous development of flagella and the complexity of the body is *Trichonympha campanula* (Figure 23). Thanks to Cleveland's brilliant investigations (Cleveland, 1923, 1924, 1925a, b, c, d) we have been furnished with an excellent example of symbiotic relations between certain of these flagellates and their hosts. Cleveland proved that the flagellates render the cellulose (in wood) eaten by termites digestible by the insects and that without the aid of the flagellates the wood eaten is not digested and the termites starve to death. By starving the termite, *Termopsis nevadensis,* and subjecting it to oxygen under pressure, Cleveland (1925d) found that the insects live indefinitely when all four species of flagellates that inhabit this insect are removed except *Leidyopsis sphærica;* that they live from three to four weeks when all are removed except *Streblomastix strix* or when all four are removed; and that they live for about ten weeks when *Trichonympha campanula* and *Leidyopsis sphærica* are removed and *Trichomonas termopsidis* and *Streblomastix strix* remain. These results indicate that *Streblomastix* is of no value to the termite, that *Trichomonas* helps keep the insect alive for a few weeks and that *Trichonympha* alone is able to complete the necessary symbiotic relationship.

CHAPTER VI

HÆMOFLAGELLATES OF MAN AND LOWER ANIMALS

The term "hæmoflagellate" as here used, includes a number of genera of the PROTOMONADINA, the members of which spend at least a part of their life-cycle in the blood of a vertebrate. Many species require two different species of hosts, living part of the life-cycle in the blood of a vertebrate and the remaining part in the intestine of an insect. Many of them are of enormous importance because they attack and bring about the death of both man and domesticated animals. Two of the genera, *Trypanosoma* and *Leishmania,* are of particular significance and will now be considered in some detail.

I. *The Genus Trypanosoma*

I. HISTORICAL

Valentine, in Berne, appears to have been the first to observe trypanosomes in the blood, having seen them in 1841 in a trout, *Salmo fario*. Two years later Gruby (1843) established the genus *Trypanosoma* for an organism that he found in the blood of frogs. (Figure 29a). The first trypanosomes of mammals were described from rats in India by Lewis (1879). Up to this time not much attention was paid to these blood-inhabiting PROTOZOA, but the genus *Trypanosoma* was brought into prominence the following year by Evans (1880) who discovered what is now known as *T. evansi* in horses and camels suffering from the disease known as surra. Fifteen years later Bruce (1895) discovered trypanosomes in horses and cattle in Africa that were suffering from the disease known as nagana. The first trypanosomes were seen in human blood by Forde in 1901 and recognized as such by Dutton in 1902. These organisms were next seen by Castellani (1903) in the cerebro-spinal fluid of a patient in Uganda who was suffering from sleeping sickness. This observation was confirmed and the relation between the trypanosomes and sleeping sickness demonstrated shortly afterward by Bruce and

Nabarro (1903). These authors, and several others, established the fact that the transmitting agent of Gambian sleeping sickness is the tsetse fly, *Glossina palpalis*. In 1905 atoxyl was introduced by Thomas as a therapeutic agent in the treatment of trypanosomiasis. Since 1903 thousands of reports have been published as a result of investigations of trypanosomes. Trypanosomes occur in certain lower animals, but not in man in North America. They are responsible for Chagas' disease in man in South America and for Gambian and Rhodesian sleeping sickness in Africa.

2. LIFE-CYCLE OF TRYPANOSOMA LEWISI

Vertebrate host. The trypanosome discovered by Lewis in rats in India is known as *T. lewisi*. It occurs in the blood of rats all over the world and appears to be non-pathogenic to these animals, since enormous numbers may be present without bringing about the appearance of symptoms. Recent detailed studies of the life-cycle of this species have been made by Taliaferro (1926) and by Taliaferro and Taliaferro (1922). When trypanosomes are inoculated into a rat a prepatent period of from two to four days ensues during which no organisms are present in the blood. Following this, multiplication stages may be found in the blood for from four to seven days. Multiplication ceases at the end of this period and all of the trypanosomes remain in what may be called the adult stage, until they die. This stage of adult infection ranges from seven to one hundred days. It has been shown by Taliaferro and by Coventry (1925) that a reaction product is built up by the rat which gradually inhibits reproduction. Not only is reproduction inhibited but at the end of about ten days after inoculation most of the trypanosomes are destroyed in the blood in some unknown way. The few that remain continue active for several weeks; finally all disappear and the rat is then immune to another infection for a considerable period, often during the rest of its life.

Invertebrate hosts. Trypanosomes are transmitted from rat to rat by the rat-flea; not by the bite of the flea, but in the feces of the flea which are licked off its fur and swallowed by the rat or in the flea itself which is eaten by the rat. We owe to Minchin and Thomson (1915) a detailed account of the life-cycle of *T. lewisi* in the flea. This is shown in Figure 24. Trypanosomes are taken into the stomach of the flea when it sucks blood from an infected rat. They lose their infectivity, probably about one-half hour afterward. Some of them succeed in penetrating epithelial cells of the stomach wall where they

undergo multiple fission and give rise to a number of daughter trypanosomes; these may reinfect epithelial cells and repeat the process or may be carried through the intestine into the rectum where they become attached by their flagella to the wall. Here they change

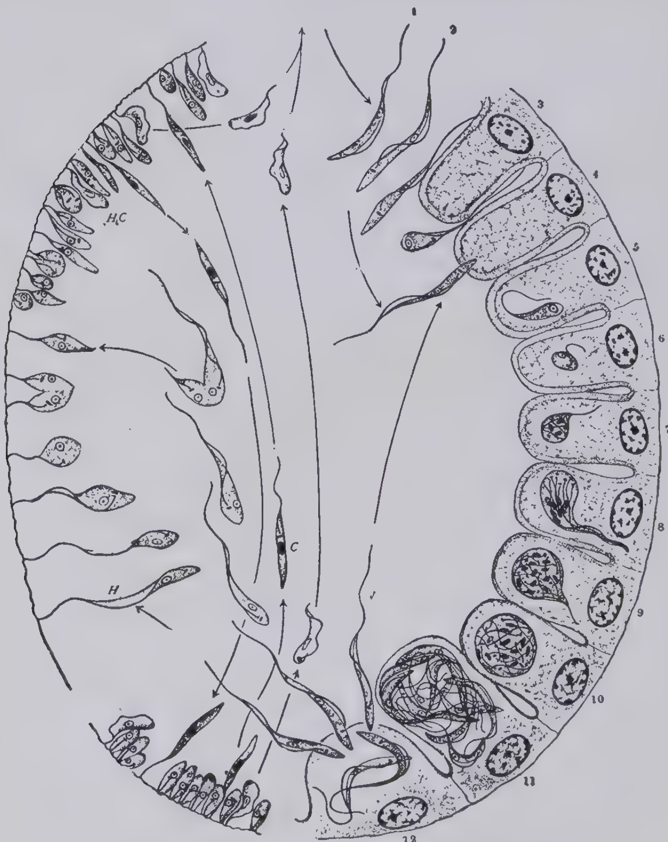


FIG. 24.—*Trypanosoma lewisi.* Cycle in the rat-flea *Ceratophyllus fasciatus.* 1, 2, blood trypanosomes entering the stomach; 3, 4, entering epithelial cells; 6-10, intracellular somatella-formation; 11, 12, trypanosomes leaving cell; *N*, young trypanosomes repeating intracellular phase; *C*, crithidial forms; *H*, haptomonads reproducing by division. (From Calkins, after Minchin and Thompson)

into crithidial forms which reproduce by longitudinal fission or transform into short, stumpy trypanosomes which constitute the infective stage passed in the feces of the flea. It requires at least five days for the development of the infective stage in the flea.

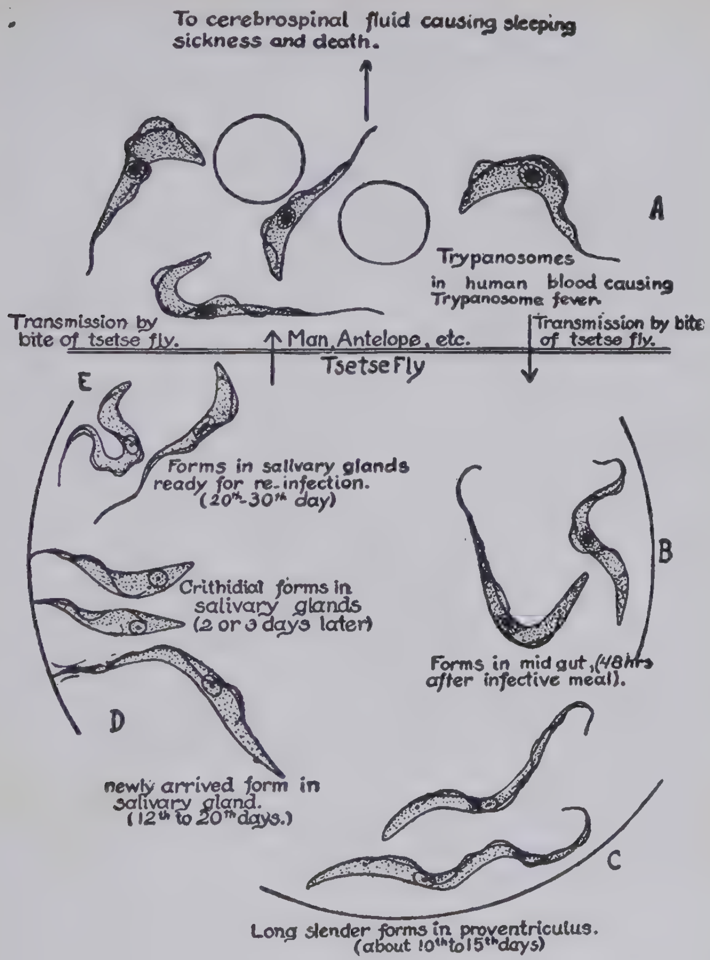


FIG. 25.—*Trypanosoma gambiense*, life-cycle in man and tsetse fly (x 1500). (From Chandler. After Robertson)

3. LIFE-CYCLE OF TRYPANOSOMA GAMBIENSE

Vertebrate host. As shown in Figure 25, *Trypanosoma gambiense*, the causative agent of Gambian sleeping sickness, spends part of its life-cycle in man or some game animal and the rest in the tsetse fly (Figure 25). The trypanosomes are inoculated into the blood of man by infected flies. Here they multiply by longitudinal division in the

blood and make their way into the cerebro-spinal fluid. When trypanosomes of this species are inoculated into rats, no reaction product that inhibits reproduction is produced, but multiplication of the organisms continue until the rat dies.

Invertebrate host. The tsetse fly, *Glossina palpalis,* becomes infected with *T. gambiense* by sucking up the blood from an infected man or animal. The organisms do not pass through an intracellular stage in the stomach, as in the case of *T. lewisi* in the flea, and do not produce infective stages in the rectum, but pass from the stomach into the salivary glands, where they pass through the crithidial stage and then transform into infective trypanosomes ready to be transmitted to another host when the fly bites.

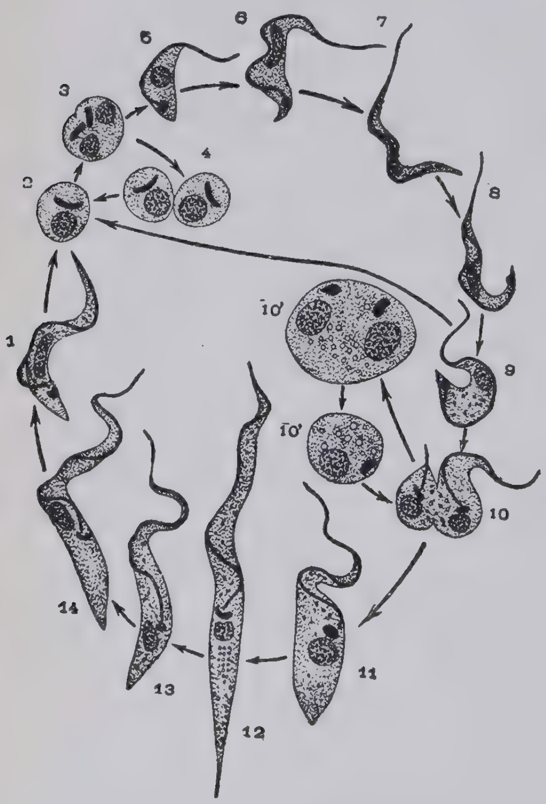


FIG. 26.—*Trypanosoma cruzi,* life-cycle in man, 2-9, and in the bug, 9-14 and 1. The infective trypanosomes from the rectum of the bug (1) become leishmanias in the tissue of man (2-4) or trypaniform stages in the blood of man (5-9). Stages taken into the digestive tract of the bug (9), divide (10), become crithidias (11, 12) and then infective trypanosomes (13, 14, 1). (After Brumpt)

4. THE LIFE-CYCLE OF TRYPANOSOMA CRUZI

Vertebrate host. Trypanosoma cruzi (Figure 26) exists in the mammalian host more frequently as a tissue parasite, a leishmania, than in the trypanosome stage. Bugs of the species *Triatoma megista* (Figure 267) are the insect vectors. The trypanosomes do not multiply in the blood of man but penetrate tissue cells,

where they transform into the leishmania forms (Figure 27) that multiply by fission. These leishmania forms may transform into trypanosomes and, when liberated into the blood, either penetrate other tissue cells or are ingested by the insect host.

Invertebrate hosts. In the stomach of the *Triatoma* the ingested trypanosomes change to the leishmania form and multiply by fission. They then transform to crithidias, which are carried into the intestine, where they multiply by fission and finally change into infective trypanosomes. It is probable that these infective trypanosomes find their way into the blood of a new host through wounds made by the bug in biting, near which the organisms have been deposited by the bug in its feces.

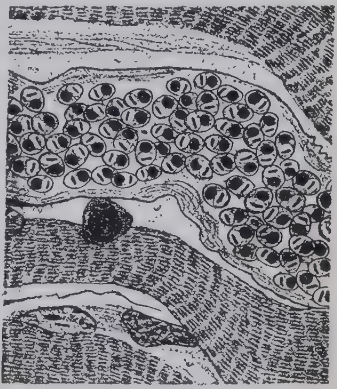


FIG. 27.—*Trypanosoma cruzi.* Leishmania stages in the muscle of the vertebrate host (x 1000). (After Brumpt)

5. HOST-PARASITE RELATIONS OF T. GAMBIENSE

Transmission. As stated above, *T. gambiense* is transmitted from man to man by the tsetse fly, *Glossina palpalis,* and perhaps several other species of this genus. The flies do not become infected until about three weeks after they have ingested trypanosomes; then they are able to transfer infective stages from their salivary glands to the blood of man during the biting process. Transmission probably also occurs from animal reservoirs, such as antelope, to man through the agency of tsetse flies.

The course of the infection. It is difficult to determine the incubation period in man because, as a rule, the time of inoculation is not known; apparently, however, this period may range from two or three weeks to seven years. There are never large numbers of trypanosomes in the blood but the numbers in a given host fluctuate from time to time. The organisms are to be found in the lymphatic glands and occur in the cerebro-spinal fluid. The first stage of the disease involves irregular fever, the enlargement of lymphatic glands and spleen, anæmia and wasting. The lethargic, or sleeping sickness, condition is reached after the trypanosomes have invaded the central nervous system.

Examination of tissues from an infective host shows the trypanosomes to be intercellular, not intracellular. They occur in various

organs, the most marked changes in these being a thickening of the arterial coat and round cell infiltration about the arteries, especially of the brain and spinal cord. Apparently the age and sex of the host has no effect on resistance to the organism.

Prevention and control. It is possible to treat successfully the first stage of trypanosomiasis but rarely the later stages. Several drugs that are more or less effective have been introduced since Thomas (1905) announced his work with atoxyl; among these may be mentioned antimony, Bayer 205 and tryparsamide. Extensive campaigns have been carried out to control the insect vectors or the animal reservoirs with a considerable degree of success.

Host-parasite specificity. Much has been learned regarding *T. gambiense* by means of studies on laboratory animals, including certain monkeys, all of which are inoculable with more or less ease. The susceptibility of laboratory animals offers a means of diagnosis since blood from a suspected human being that is infected may set up an infection when injected into such an animal. Various species of animals have been found infected with *T. gambiense* in nature, especially antelope. Cattle, sheep and dogs have also been found with infections apparently of *T. gambiense.*

FIG. 28.—*Trypanosoma rhodesiense.* Three long forms, then two in division, then five stumpy forms, the first with posterior nucleus, and the last two in division. (After Brumpt)

6. HOST-PARASITE RELATIONS OF T. RHODESIENSE

T. rhodesiense (Figure 28) was described by Stephens and Fantham (1910) as a separate species because of the presence in some specimens of a nucleus located posteriorly. About 5 to 6 per

cent of the short forms of this species exhibit this condition. As the specific name indicates, this type of sleeping sickness occurs in the Rhodesian region of Africa. Several characteristics besides the appearance of specimens with posterior nuclei indicate differences between this species and *T. gambiense*. *T. rhodesiense* is more virulent both to man and to laboratory animals; it is more resistant to drugs, such as atoxyl; it differs in its serological reactions; and is transmitted by a different species of tsetse fly, namely, *Glossina morsitans*. The relations between *T. rhodesiense* in wild and laboratory animals are similar to those of *T. gambiense*. It seems probable that *T. rhodesiense* represents members of the species *T. brucei* that have become adapted to life in the human host.

7. HOST-PARASITE RELATIONS OF T. CRUZI

T. cruzi was discovered in Brazil by Chagas (1909) in certain hemipterous insects of the genus *Triatoma* that inhabit the huts of the natives, where they find hiding places in cracks in the walls. Later, trypanosomes of this species were found in human beings. The transmitting agent is *Triatoma megista* and probably several other members of this genus. Several species of armadillos are infected in nature and serve as reservoirs. Monkeys and cats have also been found naturally infected, and infections may be set up by inoculating the organisms into many laboratory animals, including monkeys.

The disease due to the presence of *T. cruzi* is known as South American trypanosomiasis or Chagas' disease. It is acute in children under one year of age and chronic in older children and adults. The incubation period is from ten days to one month. The organisms are scanty in the blood but the disease can be diagnosed by inoculating laboratory animals. Invasion of the tissues by the parasites brings about fever, anemia and enlargement of lymph glands, the thyroid, liver and spleen. Degeneration of the invaded cells occurs and fibrous tissue is greatly increased. None of the drugs that are effective in cases of African sleeping sickness have any effect on *T. cruzi*. The best method of controlling this organism seems to be by attacking the transmitting agent.

8. TRYPANOSOMES OF LOWER ANIMALS

A large number of species of trypanosomes have been described from lower vertebrates and there are, probably, many others not yet

discovered. All of those described may not be distinct species but there is no doubt but that the members of the genus are widely distributed, both as regards species of host and the geographical distribution of these hosts.

(1) Trypanosomes of mammals. *Primates.* Trypanosomes have been discovered in many species of primates other than man and about a half dozen of these have been given specific names. Infections have been recorded in South American monkeys and marmosets, in African monkeys, chimpanzees and gorillas. Besides these natural infections it has been found that monkeys may be infected in the laboratory by blood inoculation.

Ungulates. Cattle, horses, sheep, goats, antelope and other types of ungulates are infected by various species of trypanosomes in different parts of the world. As noted above, the game animals of Africa serve as reservoirs for *T. gambiense* and *T. rhodesiense.* Some of the trypanosomes of ungulates are apparently non-pathogenic and others pathogenic. Of the non-pathogenic species two may be mentioned here. *T. theileri* occurs in cattle in South Africa and is probably transmitted by tabanid flies in which infective forms develop. *T. melophagium* is a non-pathogenic species that occurs in sheep and is transmitted by a parasitic fly known as the sheep ked.

A number of the pathogenic trypanosomes of ungulates are transmitted by tsetse flies. Of these *T. brucei, T. congolense, T. simiæ* and *T. vivax* may be mentioned. *T. brucei* is a parasite of wild game and of domestic animals; it is very virulent and accordingly very pathogenic, producing a disease called nagana. *T. congolense* occurs chiefly in cattle but also in wild game, horses and sheep. *T. simiæ* is a parasite of goats and monkeys; the wart hog serves as a natural reservoir. *T. vivax* is a pathogenic parasite of antelopes.

T. evansi and *T. equinum* are trypanosomes of ungulates that are transmitted by the proboscis of biting flies, such as *Tabanus* and *Stomoxys. T. evansi* produces a disease in horses and other animals known as surra; it was discovered by Evans in 1880 in India and has spread to various parts of the world. *T. equinum* is a species that infects horses and mules in South America and gives rise to a disease known as mal de caderas.

Of special interest is *T. equiperdum,* a parasite of horses which is responsible for a disease known as dourine; this trypanosome has no intermediate host but is transferred from one horse to another directly during coitus.

Other mammals. Many mammals belonging to other orders serve as hosts for trypanosomes. The commonest and best known species

of rodents is *T. lewisi* (see page 89). Trypanosomes have been discovered in the CHIROPTERA (bats), and INSECTIVORA (moles and shrews). Of the EDENTATA, the ant-eater is known to be infected by trypanosomes; the armadillo, as noted above, serves as a reservoir for *T. cruzi,* and the two-toed sloth serves as a host for a trypanosome-like hæmoflagellate known as *Endotrypanum schaudinni,* which lives inside of the red blood cells.

(2) BIRDS. Trypanosomes have been described from birds in various parts of the world. One of the best known is *T. paddæ* of the Java sparrow; this is a pathogenic species which can be transferred to canaries and other birds. Another well known species is *T. noctuæ* of the little owl.

(3) REPTILES. Crocodiles, turtles, snakes and lizards all serve as hosts for trypanosomes. The land-inhabiting species are transmitted by blood-sucking arthropods and the water-inhabiting species by leeches.

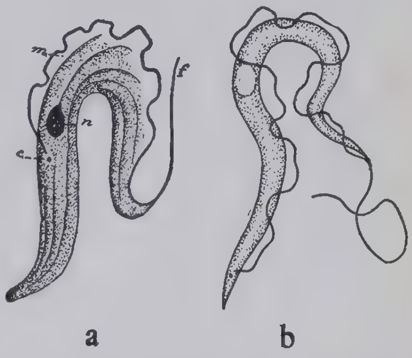


FIG. 29.—a. *Trypanosoma rotatorium* from the frog: *c*, parabasal body; *n*, nucleus; *m*, undulating membrane; *f*, flagellum (x 1400). (After Laveran and Mesnil)
b. *Trypanosoma diemyctyli* from the salamander, *Diemyctylus viridescens* (x 1600). (After Hegner)

(4) AMPHIBIA. The easiest trypanosomes to obtain in America are those of frogs, toads and salamanders. Frogs and toads are frequently infected by the type species of the genus, *T. rotatorium* (Figure 29a), and in some localities all specimens of the crimson spotted newt, *Diemyctylus viridescens,* are infected with *T. diemyctyli* (Figure 29b) (Hegner, 1921).

(5) FISH. Trypanosomes have also been described from fish. These likewise are probably transmitted by leeches. Both fresh-water and marine fish serve as hosts.

9. THE CULTIVATION OF TRYPANOSOMES

The first trypanosome to be cultivated in artificial media was *T. lewisi,* which was grown by Novy and MacNeal (1903) in a blood-agar mixture. A blood-agar medium suitable for cultivating *T. lewisi* is made up by adding 30 c.c. of 2 per cent bacteriological nutrient agar to 270 c.c. of 0.85 per cent sodium chloride solution;

10 c.c. of this mixture is placed in each test-tube, autoclaved at 120°C., then cooled at 50°C; to each is then added twenty drops of rabbit's blood and the tubes are finally ready for use after being incubated at 37°C. for twenty-four hours.

A medium widely used for growing trypanosomes is the Novy-MacNeal-Nicolle (N.N.N.) medium. This may be made up as follows: water, 900 c.c., agar, 14 grams, and NaCl, 6 grams, are mixed together during heating and a column three to four centimeters high placed in test-tubes while still hot. From 2 to 3 c.c. of sterile rabbit's blood is added to each test-tube when the agar has cooled to 50°C., mixed by revolving, and allowed to solidify in a sloped position. When incubated at 37°C. for twenty-four hours condensation liquid accumulates at the bottom of the tube; into this a small amount of infected blood or tissue is placed and the tubes incubated at from 22°C. to 25°C. Organisms may later be recovered from the liquid of condensation or from scrapings from the agar surface above the liquid. Sub-cultures should be made about every two weeks.

Many trypanosomes grown in culture media pass through stages resembling those that occur in the invertebrate host. For example. crithidia stages develop at the low temperatures; these may transform into the trypanosome stage if the temperature is increased and these may again change to the crithidia stage if the temperature is lowered. Cultivation in artificial media is of some value in diagnosis, since positive cultures are often obtained from patients in whom microscopic examination has failed to reveal the organisms. It has been found difficult to sub-culture *T. cruzi* and cultures of *T. gambiense* are not very successful, since this organism does not multiply to any great extent. *T. rotatorium,* when cultivated in blood-agar medium, rounds up, and each individual by binary division produces, after several days, a cluster of about 150 crithidia forms. This type of multiplication probably resembles what takes place in the intermediate host, the leech.

II. *The Genus Leishmania*

I. HISTORICAL

Leishmania bodies (Figure 30, C. Leis), were first seen by Cunningham (1885), who described them as parasitic organisms, in the tissue of Delhi boil in India. He supposed them to be spores contained in amœbæ, the latter really being large macrophages. In 1903 both Leishman and Donovan described similar organisms from cases

of dum-dum fever. Since then the leishmania stages have often been referred to as Leishman-Donovan bodies. Laveran and Mesnil (1903) supposed these bodies to be piroplasmas and Ross (1903), who believed them to be sporozoa, proposed the generic name Leishmania for them. The connection of *Leishmania donovani* to kala azar was discovered by Bentley in 1904. Up to this time only the leishmania stage was known, but in 1904 Rogers discovered that when spleen pulp containing Leishman-Donovan bodies was placed in sodium citrate solution at a temperature of 22°, flagellates developed of the leptomonas type. The organism of oriental sore, first described by Cunningham (1885), was rediscovered by Wright (1903) in an Armenian child in Boston. This parasite is indistinguishable from that of kala azar but has a different life history and produces different lesions in the host. Its scientific name is *Leishmania tropica.* The flagellate stage of this species (Figure 32) was obtained in cultures by Nicolle in 1908. The leishmania parasite that occurs in so-called South American leishmaniasis is by some considered to be a separate species to which the scientific name *Leishmania brasiliensis* was given by Vianna in 1911. The type of leishmaniasis that occurs in the countries bordering the Mediterranean has been considered a separate disease for which Nicolle (1908) proposed the name infantile kala azar and for the organism of which he proposed the name *L. infantum.* The evidence now available indicates that kala azar and infantile kala azar are caused by the same parasite; Noguchi (1924) finds that *L. infantum* and *L. donovani* give the same serological reactions. Leishmanias occur in dogs and cats and have been reported from lizards and several other animals.

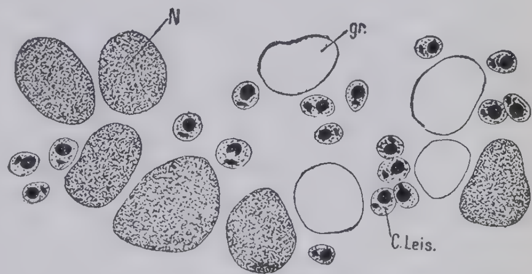


FIG. 30.—*Leishmania donovani.* Leishman-Donovan bodies in material from an infected spleen. *C. Leis.*, Leishman-Donovan body; *gr.*, red blood corpuscle; *N.*, nucleus of mononuclear cell (× 1500). (After Brumpt)

2. LEISHMANIA DONOVANI AND KALA AZAR

Geographical distribution. Kala azar occurs in various parts of Asia, including India, Ceylon, China, Russia, Turkestan and Asia

Minor; in Africa, including Tunis, Tripoli, Algeria and Egypt; and in Europe, including Greece, Italy, Spain and Portugal.

Life-cycle. As indicated in the diagram on page 81, members of the genus *Leishmania* occur as leishmania bodies in vertebrate and invertebrate hosts and as leptomonads in invertebrate hosts. As a matter of fact, there is still some doubt regarding the invertebrate host of *L. donovani* although, as noted above, the leptomonad stages occur in culture media. The flagellate stage in the life-cycle, as revealed in cultures, has the characteristics of a leptomonad. The flagellates measure from 10 μ to 20 μ in length and from 1.5 μ to 4 μ in breadth. They reproduce by binary fission. All stages between the leishmania and leptomonas forms occur in cultures. The leishmania bodies (Figures 30, 31) vary in size from 2 μ x 1 μ to 4.5 μ x 2.5 μ. They contain a spherical or slightly ovoidal nucleus near one side, a much smaller spherical or rod-shaped parabasal body and sometimes a thread-like prolongation from the parabasal body which is the rudiment of a flagellum. The leishmania bodies divide by binary fission.

FIG. 31.—*Leishmania donovani.* Leishman-Donovan bodies in the spleen cells of an infected dog (x 1500). (After Brumpt)

Host-parasite relations. As noted above, the transmitting agent of *L. donovàni* is supposed to be an invertebrate host in which the leptomonad form occurs, but this is not yet known with certainty. Bedbugs, flies, mosquitoes, lice, house-flies, ticks and sand-flies have all been accused of transmitting kala azar but none of them has yet been found guilty with certainty. Within the human body leishmanias are intracellular; they are particularly numerous in the endothelial cells of the blood and lymph capillaries and in leucocytes; they have been described from practically all organs of the body but occur especially in the spleen, liver, bone marrow and lymph glands. This distribution of the parasites among the internal organs has suggested

the name visceral leishmaniasis in contrast to cutaneous leishmaniasis which is due to *L. tropica*. The leishmania bodies are probably distributed throughout the body in the blood stream. They multiply within the cells until liberated into the blood stream by the rupture of the cell wall. They gain entrance to other cells probably by their own activity.

The incubation period of kala azar ranges from several weeks to several months, usually being difficult to determine because the time of entrance of the parasite is generally unknown. The principal symptoms produced are irregular fever, upon which quinine has no effect, enlargement of the spleen and liver, anemia and emaciation. Almost all untreated cases end in death. It seems probable that these symptoms result from the destruction of enormous numbers of cells, the disintegration products of which are liberated into the blood. Vianna in 1913 discovered tartar emetic to be effective in the treatment of South American leishmaniasis and this drug was later found to be effective also in the treatment of kala azar; most of the cases treated with this drug recover.

Cultivation and diagnosis. As noted above, Rogers (1904) succeeded in cultivating the organism of kala azar. Although the diagnosis of kala azar may be made by finding the parasite in material obtained by puncture of the spleen or in blood films stained with Romanowsky stains, the culture method is also valuable, since tubes of N. N. N. medium to which a few drops of blood are added, when incubated at 22° C. to 25° C., may reveal the parasites which may be too few in number to appear in ordinary smears.

Control. The control of kala azar may be effected in two ways, first by the treatment of all cases with tartar emetic, and second by the removal of human beings from habitations, where infection is present, to new homes. It was found by Rogers (see Rogers, 1919) that a distance of three hundred yards is sufficient to prevent the spread of kala azar although the reasons for this result are not known.

3. LEISHMANIA TROPICA AND ORIENTAL SORE

Geographical distribution. The cutaneous leishmaniasis of the old world is commonly known as Oriental sore, although it is also called Delhi boil, Bagdad boil, Aleppo boil, and so on. Oriental sore is widely distributed in Asia; it occurs in North Africa and in Spain, Italy and Greece.

Life-cycle. The leishmania stage of Oriental sore occurs within the cells of the human host. Flagellate forms have also been reported

from the sores. When leishmanias are grown in N. N. N. medium they transform into flagellates which multiply by binary fission (Figure 32). Both leishmania and leptomonas stages are indistinguishable from these stages in the life-cycle of *L. donovani.* The invertebrate hosts of *L. tropica* are supposed to be certain sand-flies of the genus *Phlebotomus* in which presumably the leptomonad stage occurs.

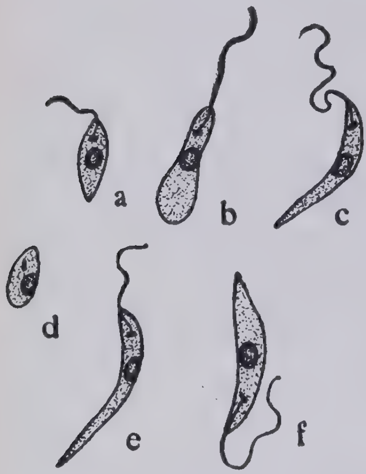


FIG. 32.—*Leishmania tropica.* Flagellate stages in culture medium (x 1480). (After Adler and Theodor)

Host-parasite relations. The organisms of Oriental sore can be transmitted from man to man by inoculation. The lesions in most cases are limited to the skin of the exposed parts of the body. One attack confers immunity. According to Manson, this fact has led the Jews of Bagdad for many years to inoculate their children in some unexposed part of the body to prevent the occurrence of scars on the face. The incubation period of Oriental sore is usually about two months. The symptoms are slight; a small red papule first appears; this increases in size and may give rise to a shallow ulcer which finally dries leaving behind it a slightly depressed scar. The leishmania bodies occur within leucocytes and epithelial cells in the papules or ulcers. Smears or cultures may be made from this material which reveal the organisms.

Control. Tartar emetic is effective against *L. tropica* as it is against *L. donovani.* It may be used in the form of an ointment applied to the lesion. Excision of the sore or the application of strong reagents such as permanganate of potash and carbolic are also effective.

4. LEISHMANIA BRASILIENSIS AND SOUTH AMERICAN LEISHMANIASIS

The fact that *L. brasiliensis* cannot be distinguished morphologically from *L. tropica* and that the lesions produced by these two organisms are similar have led many to the conclusion that they both belong to the same species. That there is a serological difference, however, is indicated by the work of Noguchi (1924) who found

that the serum from a rabbit inoculated with *L. tropica* agglutinated this organism but not *L. brasiliensis,* and that the serum from a rabbit inoculated with *L. brasiliensis* agglutinated this species but not *L. tropica.* South American leishmaniasis occurs principally in Brazil and Peru. It has also been reported from several other South American countries and from Central America. The disease is known as espundia, uta or forest yaws. The method of transmission of the organism is unknown.

5. LEISHMANIAS OF LOWER ANIMALS

Natural and laboratory infections with human species. Natural infections with human species of leishmanias are rare except in dogs. What appears to be *L. donovani* has been reported from dogs in various parts of Asia, Africa and Europe. The parasites in the dog cannot be distinguished from those in man. The disease in dogs that are naturally infected and that are inoculated with parasites from man runs the same course. Canine leishmaniasis is similar in geographical distribution to human kala azar except in India. The only other animal in which a natural infection with *L. donovani* has been reported is one case of an infected cat. Both *L. tropica* and *L. brasiliensis* have been reported in dogs living in regions where these parasites are known to be present in man.

A number of laboratory animals are susceptible to infection with all three species of human leishmanias. Dogs are easily infected; monkeys, rats, mice and guinea-pigs are more refractory. The infections in these animals develop slowly and small numbers of parasites are produced. Recently a small rodent that lives in North China, called the hamster, has been found by Smyly and Young (1924) to be especially susceptible to *L. donovani* and to bring about an extremely heavy infection. This animal may become very important as a host for carrying out laboratory experiments.

Other species of leishmanias in lower animals. A number of species of leishmanias have been described from lizards. The transmitting agents are probably insects that are eaten by these reptiles. A species known as *L. tarentolæ* occurs in the gecko in North Africa. Sand-flies, that are known to feed on the gecko, may be the transmitting agent. Other species have been reported from lizards of the genus *Anolis,* from the chameleon and from the Indian gecko, and flagellates of the leptomonas type have been reported by Strong (1924) in the intestine of Central American lizards.

CHAPTER VII

INTESTINAL FLAGELLATES OF MAN AND LOWER ANIMALS

I. *Classification and Diagnosis*

In this chapter will be considered the intestinal flagellates of man and certain of their allies in lower animals. Among these are species that live in the mouth or vagina and are hence not really intestinal flagellates; they are usually included in this category however. Five different genera are represented among these flagellates that live in man. Three species of the genus *Trichomonas* (Figure 34) belong to the family TRICHOMONADIDÆ. *Chilomastix mesnili* (Figure 33) is a member of the family CHILOMASTIGIDÆ. *Embadomonas intestinalis* (Figure 38) belongs to the family EMBADOMONADIDÆ. *Tricercomonas intestinalis* (Figure 39) has been placed in the family CERCOMONADIDÆ and *Giardia lamblia* (Figure 40) is a member of the order DIPLOMONADINA. Intestinal flagellates belonging to these genera, and perhaps in some cases even to the same species, as those just mentioned, have been reported from many types of domesticated and wild animals.

Flagellates of the genera *Trichomonas, Chilomastix* and *Giardia* are widespread among the general population. *Embadomonas intestinalis* and *Tricercomonas intestinalis* appear to be so rare that the chances of encountering them are not good. It is possible to determine the genus of the three common types just mentioned in the living condition. Material from the mouth, vagina or intestine should be stirred up in a drop of normal saline solution, confined under a cover-glass and examined with a 16 mm. objective. If active flagellates are present they will be seen moving about in this medium. The trichomonads (Figure 35) possess anterior flagella which lash backward bringing about a jerky sort of progression. Along one side is an undulating membrane, which can easily be seen with the 4 mm. objective and is the most important structural feature of use in distinguishing this genus from the others in the living condition. The flagellates are rotated on their axis by means of this undulating mem-

brane. At the posterior end of trichomonas extends out a slender hyaline rod known as the axostyle. The cell membrane of trichomonas is evidently very pliable because the shape of the organism changes frequently and pseudopodia-like projections are often extended.

Chilomastix resembles trichomonas in appearance but the shape of the body does not change to any considerable extent. It is propelled forward and spirally in a jerky manner by three anterior flagella. On one side near the anterior end is a large cytostome which can often be seen in the living animal. There is no undulating membrane and although an axostyle is absent there is frequently a spine-like projection at the posterior end that resembles the axostyle of trichomonas.

The conspicuous feature of living specimens of giardia (Figure 42) is the presence of a large sucking disc occupying the anterior ventral surface; the anterior dorsal surface of the body is correspondingly convex. Giardia does not possess an undulating membrane and the axostyles do not extend beyond the posterior end of the body. No changes in the shape of the body occur during locomotion except movements of the tail and very little progress results from the movements of the flagella.

II. *Chilomastix in Man*

1. LIFE-CYCLE

One species of the genus *Chilomastix,* known as *Chilomastix mesnili,* occurs in man. This form lives in the large intestine and is present in about 10 per cent of the general population in many parts of the world. Cysts are formed in the intestine, pass out in the feces and represent the stage that brings about infection in new hosts. The trophozoites multiply by binary fission and division has been reported within the cyst.

2. MORPHOLOGY

Trophozoite (Figure 33a). The living trophozoite of *Chilomastix mesnili* has been described above; its principal characteristics are presented in the table on page 118. The body is pear-shaped and ranges usually from 10 μ to 15 μ in length and from 3 μ to 4 μ in breadth. There are three anterior flagella and a fourth flagellum that is situated in the cytostome and directed posteriorly. The cytostome is almost half as long as the entire body; along either side of it is a supporting fibril. Near the anterior end of the body is a large

spherical nucleus containing one or several blocks of chromatin and on the outside of the nuclear membrane are located several blepharoplasts from which the flagella arise. The food of chilomastix consists largely of bacteria and the cytoplasm is usually so crowded with food vacuoles that the structures just described are often obscured.

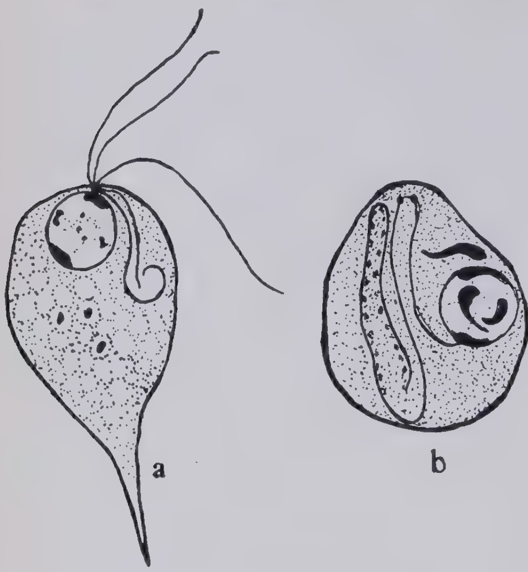


FIG. 33.—*Chilomastix mesnili.* a. Trophozoite. b. Cyst (x 4000). (After Hegner)

Cysts. The cyst of chilomastix in the living condition is lemon-shaped and usually from 7 μ to 9 μ in length and from 4 μ to 6 μ in breadth. Practically no structure can be seen within the living cyst. In specimens fixed in Schaudinn's solution and stained with iron-hæmatoxylin (Figure 33b) the wall of the cyst is seen to be thickened at the anterior end and separated slightly from the protoplasmic body within. Food bodies are extruded before encystment takes place, hence the nucleus and cytostomal structures are often more conspicuous in the cyst than in the trophozoite.

3. HOST-PARASITE RELATIONS

Chilomastix mesnili is transmitted from man to man in the cyst stage and infections are the result of the ingestion of contaminated food or drink. Cysts will live for months in water and apparently retain their infectivity (Boeck, 1921). They are probably often carried to food or drink by flies, since these insects readily ingest fecal material and the cysts may be deposited later in a viable condition (Root, 1921). A disease known as flagellate diarrhea has been attributed to the presence of *C. mesnili* because these flagellates have been found in persons suffering from diarrhea, in which no

other causative organism could be discovered. It has not yet been definitely proved, however, that chilomastix is guilty.

III. *Chilomastix in Lower Animals*

Chilomastix occurs in many of the lower animals. It has been reported from the chimpanzee and orang-utan and several species of monkeys, from the rumen of the goat, the cecum of the rabbit, rat and guinea-pig, the cecum of the fowl, and from the intestine of the lizard, frog and fish. Separate specific names have been applied to these various types but whether they all represent "good" species is still to be determined. They resemble *Chilomastix mesnili* in general features.

IV. *Trichomonas hominis*

1. LIFE-CYCLE

This species is known only in the trophozoite stage. It lives in the large intestine and probably is present in about 10 per cent of the general population in various parts of the world.

2. MORPHOLOGY

The most common trichomonad that lives in the human intestine possesses four anterior flagella, but specimens with three or five are sometimes found. The offspring of these, when grown in culture, have the same number of flagella as their parents, that is, the number of flagella appears to be a constant characteristic. It has been proposed that these three types of intestinal trichomonads be considered as belonging to three different genera, in which case the type with four flagella retains the name *Trichomonas hominis*, that with three must be placed in the genus *Tritrichomonas* (Figure 35) and the form with five in the genus *Pentatrichomonas* (Figure 34a). These three types are considered in this book together under the name *Trichomonas hominis*.

As indicated in the table on page 118, *Trichomonas hominis*, when fixed in Schaudinn's solution and stained with iron-hæmatoxylin, exhibits, besides the anterior flagella, a flagellum that is attached to the outer edge of the undulating membrane and becomes free at the posterior end of the body. On one side near the anterior end is a comma-shaped cytostome; a hyaline rod, the axostyle, passes through the center of the body longitudinally. Near the

anterior end is a spherical nucleus, several blepharoplasts from which the flagella arise and a chromatic basal rod which arises from a blepharoplast and extends posteriorly at the base of the undulating

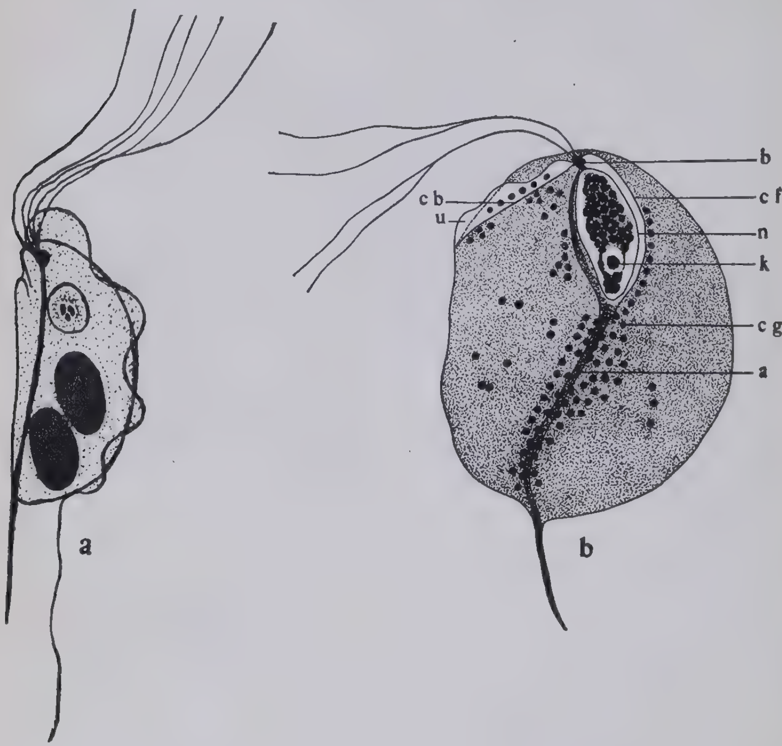


FIG. 34.—a. *Pentatrichomonas ardindelteili* (x 3000). (After Hegner)
b. *Trichomonas vaginalis:* a, axostyle; b, blepharoplastic granules; cb, chromatic basal rod; cf, cytostomal fiber; cg, chromatic granule; k, karyosome; n, nucleus; u, undulating membrane (x 3000). (After Hegner)

membrane. The body of *T. hominis* varies greatly in size but is usually from 8 μ to 15 μ in length and from 3 μ to 5 μ in breadth.

3. HOST-PARASITE RELATIONS

Since there is apparently no cyst stage in the life-cycle of *T. hominis,* this species must be transmitted from one person to another in the trophozoite form, and the only conceivable method of entrance to the host is in contaminated food or drink. It is obviously neces-

sary, if this is correct, for the trophozoite to withstand the digestive juices in the stomach and to pass through the small intestine unharmed before an infection can be established in the large intestine. That this is probable has been shown in the case of rats, cats and guinea-pigs (Hegner, 1924, 1926; Brumpt, 1925; Wenricl and Yanoff, 1927) to which were fed trichomonads that were later recovered in a viable condition from the intestine.

FIG. 35.—*Tritrichomonas fecalis* from human feces. Photograph of living specimen with dark field illumination. Notice three anterior flagella, undulating membrane, flagellum at end of undulating membrane, and axostyle. (After Cleveland)

The resistance of *T. hominis* to conditions outside of the body have recently been demonstrated by a series of experiments (Hegner, 1928). It was found that viable trichomonads could be recovered from the fecal material in which they passed out of the body eight days later, the fecal material in the meantime being kept at room temperature (22° C.), summer temperatures (25° C. and 31° C.) and low temperature (5° C.). Viable trichomonads were also recovered at the end of seven days from fecal material deposited on garden soil. When fecal material is highly diluted with water, however, the osmotic pressure is so greatly changed that death occurs within a few hours, hence the danger of becoming infected through drinking water appears to be slight.

Experiments on the transmission of *T. hominis* by cockroaches and house-flies (Wenyon and O'Connor, 1917; Root, 1921; Hegner, 1928) indicate that there is little danger of trichomonads surviving ingestion by cockroaches, but that flies that ingest fecal material may deposit living trichomonads in their vomit or droppings at intervals of from twenty minutes to four hours after ingestion. It seems probable, therefore, that the house-fly plays an important rôle in the transmission of this flagellate.

The question of the pathogenicity of *Trichomonas hominis* has not yet been decided. This species has been accused of causing flagellate diarrhea and dysentery. The five-flagellate pentatrichomonas (Figure 34a) was reported from a number of diarrheic or dysenteric patients and hence considered particularly pathogenic, but recently a case was described (Hegner, 1925) of a person infected with this form who had never exhibited any symptoms of diarrhea or dysentery. The habit of pentatrichomonas of ingesting red cells has also been advanced as evidence of pathogenicity, but recent experiments (Hegner, 1928) prove that many types of trichomonads ingest red cells and that these are accepted for food just as are bacteria and other food particles.

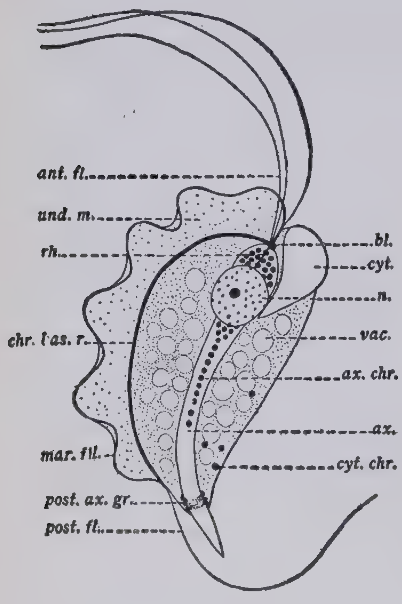


FIG. 36.—*Tritrichomonas augusta* from the frog. *ant. fl.*, anterior flagella; *ax.*, axostyle; *ax. chr.*, axostylar chromidia; *bl.*, blepharoplast; *chr. bas. r.*, chromatic basal rod; *cyt.*, cytostome; *cyt. chr.*, cytoplasmic chromidia; *mar. fil.*, marginal filament; *n.*, nucleus; *post. ax. gr.*, posterior axostylar granules; *post. fl.*, posterior flagellum; *rh.*, rhizoplast connecting blepharoplast and nucleus; *und. m.*, undulating membrane; *vac.*, food vacuole (x 1500). (After Kofoid and Swezy)

V. *Trichomonas buccalis*

1. LIFE-CYCLE

Trichomonas buccalis is an inhabitant of the human mouth and apparently exists only in the trophozoite stage. It divides by binary longitudinal fission and multiple fission has also been reported (Ohira and Noguchi, 1917). No other stages in the life-cycle of this species have been observed.

2. MORPHOLOGY

The trophozoite of *T. buccalis* varies in size from 5 μ to 21 μ in length and from 4 μ to 8 μ in breadth. There are four anterior flagella which arise in pairs from two blepharoplasts. The undulating membrane extends posteriorly only about two-thirds the length of the body and the flagellum on its outer edge does not extend beyond the end of the membrane. The chromatic basal rod is inconspicuous. The axostyle is thread-like and stains deeply in iron-hæmatoxylin. A

clear area, sometimes visible near the anterior end, may be a cytostome. The nucleus is similar in position and structure to that of *T. hominis*.

3. HOST-PARASITE RELATIONS

Trichomonas buccalis may be found in scrapings from the gingival space at the base of the teeth. They are not commonly found in smear preparations, but may be cultivated in serum-saline-citrate medium; the data obtained in this way indicate a high incidence of infection; probably 50 per cent of the general population carry this organism. Transmission, no doubt, usually occurs during kissing. Recent investigations indicate a definite relation between the presence of *T. buccalis* and a diseased condition of the oral region (Hogue, 1926; Hinshaw, 1926); that is, more positive cases have been recorded from persons giving a history of pyorrhea, acute gingivitis or abscessed teeth than from those with normal mouths. The flagellate itself is probably not pathogenic but finds the diseased condition favorable for growth and multiplication.

VI. *Trichomonas vaginalis*

1. LIFE-CYCLE

This is the type species of the genus *Trichomonas*. It occurs only in the trophozoite stage. It is widespread among women and a high incidence of infection has been reported (Brumpt, 1913; Reuling, 1921; Hegner, 1925), from 5 per cent to 50 per cent being infected. A few cases of infection have been reported from the urinary tract of man (Dock, 1896; Hegner and Taliaferro, 1924; Katsunuma, 1924; Dastider, 1925).

2. MORPHOLOGY

The length of *Trichomonas vaginalis* varies from 7 μ to 21 μ and the breadth from 6 μ to 18 μ. The four anterior flagella usually emerge from the body in pairs. The organism (Figure 34b) resembles the other trichomonads in structure but has a very short undulating membrane with a flagellum on its outer edge that does not extend beyond the side of the body. The chromatic basal rod is thin and the axostyle is likewise thin and stains deeply with iron-hæmatoxylin. Surrounding the axostyle are a number of spherical bodies that stain deeply with iron-hæmatoxylin.

3. HOST-PARASITE RELATIONS

How *Trichomonas vaginalis* is transmitted from one host to another is unknown. Specimens could easily gain access to the urinary tract of man during coitus. Recent investigations on monkeys indicate that the intestinal and vaginal trichomonads may belong to the same species (Hegner, 1928). If this is true, then the vagina may become infected by contamination with the intestinal form. The pathogenicity of *T. vaginalis* is also uncertain. Flagellates of this species are reported to be present when the vaginal mucous membrane is in an abnormal condition and when the reaction of the vaginal mucus is acid. Treatment with sodium bicarbonate is therefore recommended by some physicians so as to change the vaginal contents to an alkaline condition.

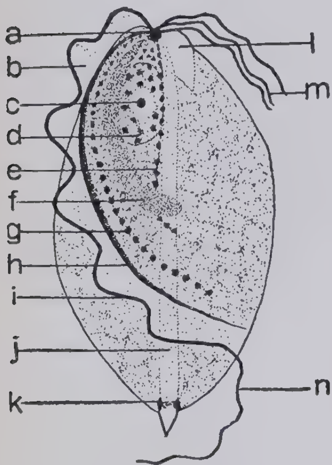


FIG. 37.—*Tritrichomonas muris* from the rat. Partly diagrammatic figure, showing, a, blepharoplast; b, undulating membrane; c, karyosome; d, nucleus; e, inner row of chromatic granules; f, parabasal body; g, outer row of chromatic granules; h, chromatic basal rod; i, posterior flagellum as chromatic margin of undulating membrane; j, axostyle; k, chromatic ring at point of emergence of axostyle; l, cytostome; m, anterior free flagella; n, posterior free flagellum. (After Wenrich)

I. *Trichomonads in Lower Animals*

Most of the mammals closely associated with man appear to be infected with trichomonads; flagellates belonging to this genus are commonly present in the intestine of rats, mice, guinea-pigs, rabbits, dogs and cats. They have also been reported from the mouth of the dog (Hegner and Ratcliffe, 1927), from the stomach of the pig, the rumen of cattle, the cecum of fowls, the intestine of reptiles, amphibia and fish and from leeches, molluscs and termites. Trichomonads have been reported from the intestine of various species of monkeys and from the vagina of the rhesus monkey, *Macacus rhesus*, and the intestinal form from the latter has apparently been successfully transmitted to the vagina of the same species of monkey (Hegner, 1928). The species most easily obtained for study are *Tritrichomonas augusta* (Figure 36), from the rectum of the frog, and *Tritrichomonas muris* (Figures 37 and 42), from the cecum of the rat. Both of these organisms are more easily prepared for study than is

T. hominis from man and exhibit the characteristics of the genus much more distinctly. Of special interest in connection with the trichomonads of lower animals is the fact that a cyst stage occurs in the life-cycle of certain species and that multiple fission as well as binary fission may occur. During multiple fission the two daughter flagellates do not separate following division and their offspring likewise remain together until a so-called somatella is formed consisting of eight merozoites. Eventually these separate one by one from the somatella.

VIII. *Embadomonas intestinalis*

This species was first reported by Wenyon and O'Connor (1917) from two cases in Egypt. It is apparently a rare species in man but has been found in widely separated regions. It probably lives in the large intestine. Both trophozoites and cysts occur (Figure 38) and infections may last for at least six weeks. The trophozoite is ovoidal and from 4 μ to 9 μ in length and 3 μ to 4 μ in breadth. It is characterized by the presence of two flagella, one extending out from the anterior end and the other, which is much thicker, arising from the large cytostome which is situated on one side and extends from near the anterior end to about the middle region of the body. Near the anterior end is a spherical nucleus containing a large karyosome. The cysts are pyriform in shape, 4 μ to 6 μ in length and 3 μ to 4 μ in breadth.

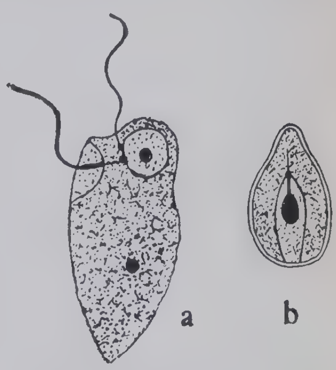


Fig. 38.—*Embadomonas intestinalis* from man. a. Trophozoite. b. Cyst (x 4500). (After Wenyon and O'Connor)

IX. *Embadomonas in Lower Animals*

The genus *Embadomonas* was established for a flagellate discovered by MacKinnon (1911) in larvæ of the crane fly. Since then specimens belonging to this genus have been recorded from a waterbug, frog and tortoise. Wenyon (1926) records specimens from the cecum of the guinea-pig and wild rat morphologically identical with *E. intestinalis* in man. Specimens have been reported from at least two species of monkeys (Fonseca, 1917; Kessel, 1927) and from the sheep and three-toed sloth (Hegner and Schu-

maker, 1928). Whether these differ specifically from *E. intestinalis* is still to be determined.

X. *Tricercomonas intestinalis*

The genus *Tricercomonas* was founded by Wenyon and O'Connor (1917) for a single species, *Tricercomonas intestinalis,* which was discovered in diarrheic stools in Egypt. It has since been reported from North America, Malaya and Brazil. The trophozoite (Figure 39a) is pear-shaped and has the structure characteristic of the genus *Cercomonas,* but possesses three anterior flagella and a posterior flagellum which is attached to the flattened side of the organism. The length of the trophozoite varies from 4 μ to 10 μ and the breadth from 3 μ to 6 μ. There is no cytostome. There is a large anterior nucleus of the vesicular type. Reproduction is by longitudinal binary fission. The cysts of *T. intestinalis* (Figure 39b) are elongate oval, 6 μ to 8 μ in length and 3 μ to 4 μ in breadth. Only about one hundred cases of infection with this organism have been reported and nothing is known regarding its relations to the human host. Considerable confusion exists regarding this species and one named *Enteromonas hominis* by Fonseca (1915). It seems probable that organisms that have been found in man and in the guinea-pig and placed in the genus *Enteromonas* have either been specimens of *T. intestinalis* or of some other species of flagellate.

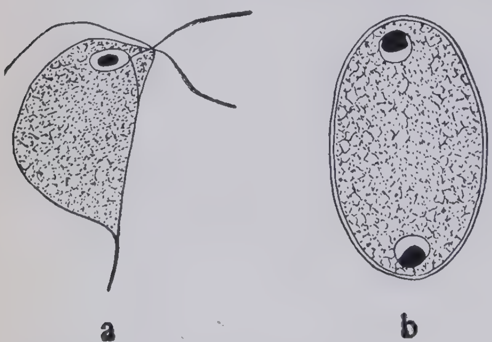


FIG. 39.—*Tricercomonas intestinalis* from man. a. Trophozoite. b. Cyst (x 4500). (After Wenyon and O'Connor)

XI. *Giardia lamblia*

1. LIFE-CYCLE

The species of giardia living in man possesses both trophozoite and cyst stages in its life-cycle. The trophozoites divide by binary fission and division also occurs within the cyst. The surveys of in-

testinal protozoa made in various parts of the world indicate that *Giardia lamblia* is present in about 12 per cent of the general population. Infection is brought about by the ingestion of cysts, which excyst in the small intestine and remain in the duodenum; this is the section of the digestive tract where these flagellates are usually located.

2. MORPHOLOGY

Trophozoite (Figure 40a). The trophozoite of *Giardia lamblia* is 9 μ to 20 μ in length and 5 μ to 10 μ in breadth; it is broadly pear-shaped and bilaterally symmetrical. There is a large anterior ventral sucking disc, as shown in Figure 42, two nuclei, two axostyles and four pairs of flagella. The two anterior lateral flagella arise from blepharoplasts at the anterior ends of the axostyles, pass forward through the cytoplasm, cross each other near the extreme anterior end, follow the edge of the body for a short distance and then emerge one on either side. The posterior lateral flagella have a similar origin but pass posteriorly along the edges of the lateral shields and emerge near the posterior end of the body. The caudal flagella extend out from the caudal ends of the axostyles, and the ventral flagella arise directly from the axostyles a short distance posterior to the nuclei. Between the two blepharoplasts is an arch-shaped fibril in the center of which is an interblepharoplastic granule. A rhizoplast connects each nucleus to the blepharoplast on its side of the body. Just posterior to the ventral sucking disc are a pair of parabasal bodies that are more or less intimately fused together. Basal granules are sometimes visible at the points where the anterior lateral and caudal flagella emerge

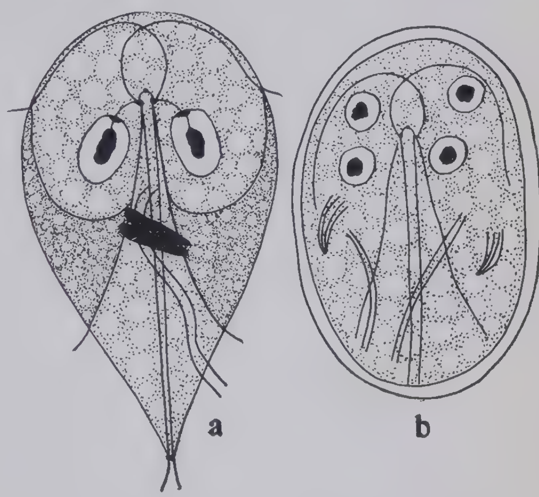


Fig. 40.—*Giardia lamblia* from man. a. Trophozoite. b. Cyst (x 4000). (After Hegner)

from the body. The diamond-shaped region between the lateral shields is much thinner than the rest of the body. The ventral sucking disc is used by the organism to attach itself to epithelial cells of the intestine and no doubt helps it to maintain itself in the duodenum against the action of peristalsis. While thus located, the ventral flagella are in active movement, thus creating a current which renews the medium and is probably valuable in bringing nutritive material to the flagellate. There is no cytostome, food substances being absorbed through the general surface of the body.

Cyst (Figure 40b). The cyst of *G. lamblia* is ovoidal and varies from 8 μ to 14 μ in length and from 6 μ to 10 μ in breadth. Fibrils are visible in the living cyst. In cysts that are fixed in Schaudinn's solution and stained with iron-hæmatoxylin the axostyles and cytoplasmic portions of the anterior lateral and posterior lateral flagella are visible as well as groups of fibrils which probably are the remains of those that lie along the edge of the sucking disc and lateral shields in the trophozoite. There may be two, four, eight or sixteen nuclei within the cyst; these are spherical and are usually distributed, two near the anterior end, two near either end, four near the anterior end or four near either end. Excystation has recently been described (Hegner, 1927).

3. HOST-PARASITE RELATIONS

Transmission. As in other intestinal protozoa that have a cyst stage in their life-cycles, *Giardia lamblia* is transmitted from one human host to another by the contamination of food or drink by cysts. The work of Boeck (1921) indicates that these cysts may remain alive outside of the body for several months. They are unable, however, to withstand drying, hence their infectivity depends upon the continued presence of moisture.

Pathogenicity. The terms "lambliasis," "giardiasis" and "flagellate diarrhea" all refer to a pathogenic condition supposed to be brought about by *G. lamblia.* It is still to be proved, however, that this flagellate is responsible for the symptoms of diarrhea observed. It seems probable that the organisms find the diarrheic condition favorable for their growth and multiplication. Most of the persons infected with *G. lamblia* do not exhibit symptoms but must be considered carriers in whom the organisms multiply and produce cysts, the latter being passed by the host and responsible for the initiation of new infections. Recently cholecystitis or inflammation of the gall bladder has been attributed to these flagellates (see Hegner, 1927).

Children appear to be more heavily infected with *G. lamblia* than do adults, a fact which indicates an age resistance to the organism.

XII. *Giardia in Lower Animals*

Species of the genus *Giardia* have been reported from a large number of lower animals including monkeys, lions, cats, dogs, sheep, cattle, goats, horses, rabbits, guinea-pigs, rats, mice, herons, lizards, tadpoles, fish and nematodes (Figure 41). These resemble *Giardia*

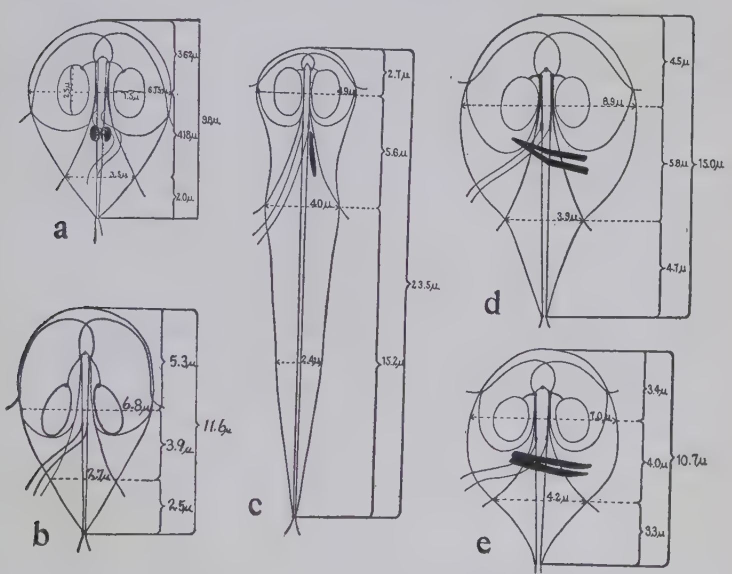


FIG. 41.—Giardias from lower animals. Diagrams drawn to scale to illustrate differences in size, shape, parabasal bodies, and other structural features (x 2600). (After Hegner)
a. *Giardia muris* from the rat.
b. *Giardia sp.* from the great blue heron.
c. *Giardia agilis* from the tadpole.
d. *Giardia duodenalis* from the rabbit.
e. *Giardia caviæ* from the guinea-pig.

lamblia in the general structure of both the trophozoite and cyst, but careful measurements indicate differences in body size and differences in the relative shape and size of various parts of the body. The number, size, shape and location of the parabasal bodies also differ in the organisms from different species of hosts. Because of these morphological differences many of these forms are considered to

TABLE II

INTESTINAL FLAGELLATES OF MAN

	Trophozoite			*Cyst*	
	Structural Characteristics	*Shape*	*Size*	*Shape*	*Size*
1. *Chilomastix mesnili* (Wenyon, 1910)	3 free ant. flag; 1 flag. in cytostome	Pear-shaped	10 μ-15 μ x 3 μ-4 μ	Lemon-shaped	7 μ-9 μ x 4 μ-6 μ
2. *Trichomonas hominis* (Davaine, 1860)	3, 4 or 5 free ant. flagella; 1 post. flag. on margin of undulating membrane; axostyle present	Pear-shaped	8 μ-15 μ x 3 μ-5 μ	Cysts unknown	
3. *Trichomonas vaginalis* Donné, 1837		Pear-shaped	7 μ-21 μ x 6 μ-18 μ	Cysts unknown	
4. *Trichomonas buccalis* (Goodey, 1917)		Pear-shaped	5 μ-21 μ x 4 μ-8 μ	Cysts unknown	
5. *Embadomonas intestinalis* (Wenyon and O'Connor, 1917)	2 ant. free flag. unequal in thickness; cytostome large	Ovoid	4 μ-9 μ x 3 μ-4 μ	Pyriform	4 μ-6 μ x 3 μ-4 μ
6. *Tricercomonas intestinalis* Wenyon and O'Connor, 1917	3 ant. free flag.; one post. flag. on surface of body	Pear-shaped	4 μ-10 μ x 3 μ-6 μ	Elongate oval	6 μ-8 μ x 3 μ-4 μ
7. *Giardia lamblia* (Stiles, 1915)	Bilaterally symmetrical; anterior ventral sucking disc; 2 nuclei, 2 axostyles, 4 pairs of flagella	Pear-shaped	9 μ-20 μ x 5 μ-10 μ	Oval	8 μ-14 μ x 6 μ-10 μ

be distinct species. Apparently host-parasite specificity is very rigid among members of the genus *Giardia* since almost every host species is infected by a distinct species of the genus (Hegner, 1927). *Giardia muris* of the rat (Figure 41a) is the species most easily obtained.

FIG. 42.—Flagellates from the intestine of the rat as seen when alive. (After Hegner)
1. *Giardia muris.*
2. *Hexamita muris.*
3. *Tritrichomonas muris.*

Trophozoites occur in the duodenum of a considerable proportion of laboratory rats and mice. Encysting specimens may be found in the small intestine and cysts may be recovered from the cecum or the feces. *G. muris* differs in only minor respects from *G. lamblia.* Another species that can easily be obtained, and is very distinctive in shape and structure, is *G. agilis* which occurs in the duodenum of tadpoles (Figure 41c).

CHAPTER VIII

SPOROZOA IN GENERAL AND GREGARINES IN PARTICULAR

I. *Classification*

The groups of protozoa that are brought together in the class SPOROZOA have certain characteristics in common but are not necessarily closely related. They are combined in one class largely for the sake of convenience. Sporozoa are all parasitic. They are especially common among vertebrates and arthropods and less common among other invertebrates. They form spores at one stage in their life-cycle which usually serve to set up infections in new hosts. There are no locomotor organelles in the adult stage and food is absorbed through the general surface of the body. The following is a convenient arrangement of the groups in this class:

Class SPOROZOA. All species parasitic; locomotor organs absent, sexual reproduction results in the formation of sporozoites.

- Subclass 1. TELOSPORIDIA. Intracellular during part of the life-cycle; spore formation ends the life of the individual.
  - Order 1. GREGARINIDA. Inhabitants of cavities (cœlozoic); schizogony usually omitted from life-cycle.
  - Order 2. COCCIDIA. Typically inhabitants of epithelial cells (cytozoic); both schizogony and sporogony occur in a single host.
  - Order 3. HÆMOSPORIDIA. Blood-inhabiting species (cytozoic) of vertebrates; schizogony in a vertebrate and sporogony in an invertebrate host; resistant spores usually absent.
- Subclass 2. NEOSPORIDIA. Usually multinucleate in adult stage; spore formation occurs during the life of the individual.
  - Order 1. MYXOSPORIDIA. Adult, a large multinucleate plasmodium; spores large, with usually two polar capsules.

Order 2. MICROSPORIDIA. Spores small, with usually one polar capsule.

Order 3. SARCOSPORIDIA. Spores in sac-like tubules in muscle cells of vertebrates.

II. *Life-Cycles*

The life-cycles of the sporozoa are as a rule more complex than those of protozoa belonging to the other three classes. This is apparently the result of the fact that there is often an alteration of hosts, part of the life-cycle being passed in a vertebrate and part in an invertebrate. In a typical life-cycle two sorts of reproduction occur. Schizogony, during which large numbers of offspring are produced asexually, and sporogony, which involves sexual phenomena and ends in the production of spores.

Various types of life-cycles will be described in this and the following chapters, hence it is not necessary to describe them here in detail. It may, however, be worth while to review briefly three typical but different life-cycles.

1. MONOCYSTIS

Certain gregarines of the genus *Monocystis* are parasitic in the seminal vesicles of the earthworm. The entire life-cycle (Figure 43) is passed in a single host. The trophozoite penetrates and grows at the expense of a group of sperm mother cells. There is no asexual reproduction of the trophozoite but two fully grown trophozoites conjugate and surround themselves with a double wall, thus forming a cyst; within, the organisms, which now may be considered gametocytes, produce large numbers of gametes; these copulate in pairs and form spores, the resistant wall of which is known as a sporocyst; within each spore eight spindle-shaped sporozoites arise; these represent the stage that infects new hosts.

2. ISOSPORA

Another type of life-cycle that includes asexual reproduction in the trophozoite stage may be illustrated by means of the coccidium of the cat and dog, *Isospora felis* (Figure 46). The sporozoites that escape from the sports in the intestine of the host (30) penetrate epithelial cells of the intestinal wall (1) and become trophozoites (2); each trophozoite is a schizont which produces a number of daughter

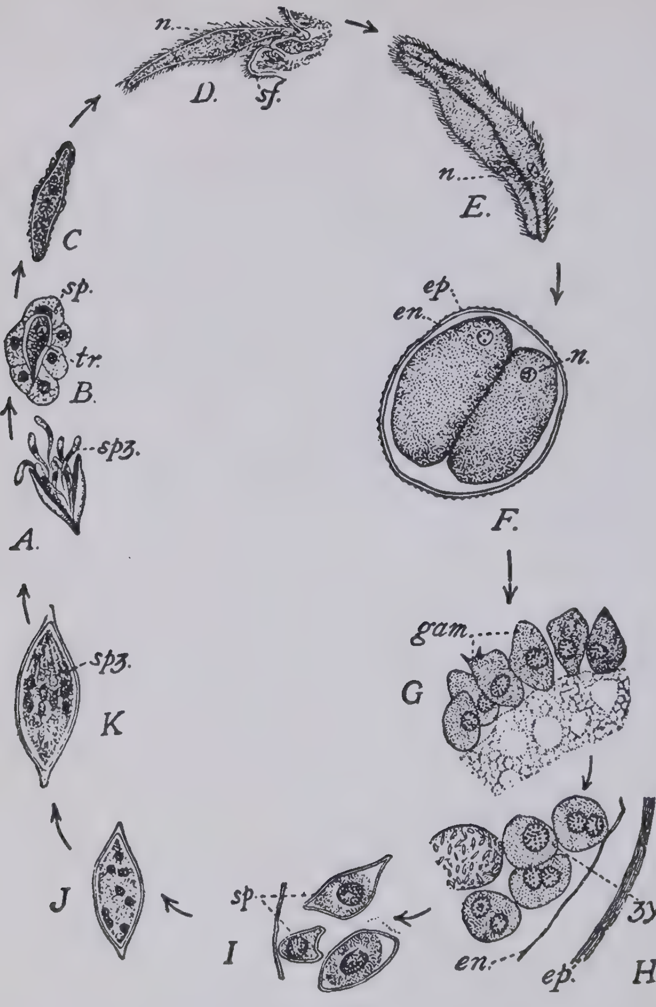


FIG. 43.—*Monocystis,* an acephaline gregarine parasitic in the seminal vesicles of the earthworm. A, the eight sporozoites (*spz.*) escaping from the sporocyst. B, a young trophozoite (*tr.*) among the sperm-mother cells (*sp.*) of the earthworm. C, a free individual with a few withered sperm cells adhering to it. D, a mature individual attached to the sperm-funnel (*sf.*) of the earthworm. E, two mature individuals joined side by side. F, two individuals have formed a cyst; *en.*, endocyst; *ep.*, epicyst; *n.*, nucleus. G, gametes (*gam.*) formed by one individual within the cyst. H, conjugation of gametes to form zygotes (*zy.*). I, zygotes (sporoblasts, *sp.*) that have secreted spore coats or sporocysts. J, a single spore in which the nucleus has divided, forming eight daughter nuclei. K, a fully developed spore containing eight sporozoites (*spz.*). (From Hegner. After Cuénot and Bourne)

merozoites asexually (3-8); this multiplicative process is known as schizogony. The merozoites may enter other epithelial cells (8 to 1) becoming trophozoites and pass through another period of asexual reproduction, or, after the penetration of epithelial cells, may produce merozoites which are gametocytes; these penetrate other epithelial cells (9) where they develop into macrogametocytes (19) or microgametocytes (11). Each merozoite produces either one large macrogamete (22) or a large number of microgametes (18). One microgamete copulates with each macrogamete (23), a process that may be considered fertilization, thus producing a zygote. A wall forms about the zygote and the body is then known as an oöcyst (24). The protoplasm within divides to form two sporoblasts (28) each of which forms a sporocyst about itself thus becoming a spore (29). Within each spore four sporozoites develop (29). This life-cycle, which is passed in a single host, includes a period of asexual reproduction, known as schizogony, followed by sexual processes which lead to a second type of reproduction ending in the formation of spores and sporozoites.

3. MALARIA PARASITE

The third type of life-cycle, well illustrated by that of the malaria parasites (Figure 50), involves stages similar to those just described, but part of them are passed in a vertebrate host, for example man, and the rest in an invertebrate host, for example certain anopheline mosquitoes. Sporozoites inoculated into the blood by the mosquito penetrate red cells, becoming trophozoites; these are schizonts which produce merozoites by asexual reproduction. Some of the trophozoites become gametocytes; these do not undergo development in the human body, but, in the stomach of the mosquito, each macrogametocyte produces one macrogamete and each microgametocyte produces a number of microgametes. Copulation (fertilization) then occurs, an oöcyst is formed, and large numbers of sporozoites develop within it.

III. *Gregarines*

Gregarines are among the simplest of the sporozoa and are easily obtained for study, since they are common parasites in the digestive tract and body cavity of insects and earthworms. We may recognize two groups, the first known as the EUGREGARINIDA which do not have a period of schizogony in their life-cycle, and the SCHIZOGREGARINIDA which do.

1. ACEPHALINE GREGARINES

These are gregarines without an epimerite or "head." The species of the genus *Monocystis,* the life-cycle of which was described on page 121 (Figure 43), are common in the seminal vesicles of the earthworm. If the seminal vesicles of the worm are dissected out, cysts containing spores and large trophozoites may usually be found, as well as other stages in the life-cycle.

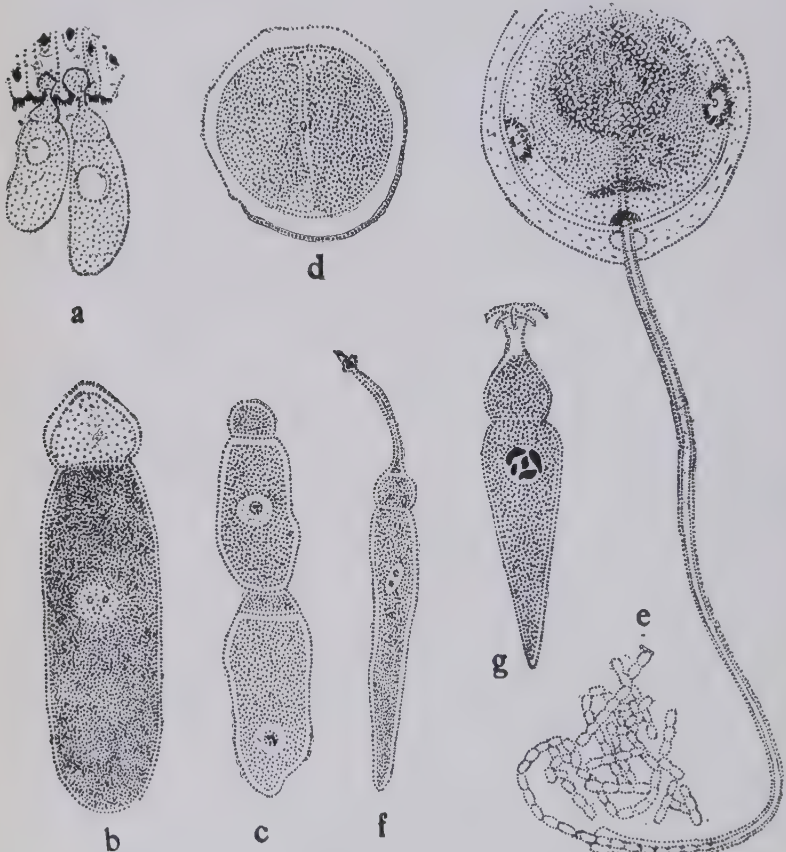


FIG. 44.—Cephaline gregarines of insects. (After Watson)
a. Trophozoites of *Leidyana erratica* attached to host cells of the cricket (x 245).
b. Adult sporont of *Leidyana erratica* (x 245).
c. Sporonts of *Gregarina blattarum* of the cockroach in syzygy.
d. Two sporonts of *Leidyana erratica* within a cyst (x 60).
e. Mature cyst of *Leidyana erratica* extruding a chain of spores (x 245).
f. *Stylocephalus longicollis* of the church-yard beetle.
g. *Ancyrophora uncinata* of the water-beetle.

2. CEPHALINE GREGARINES

These are especially abundant in insects and can be obtained easily from the intestine of grasshoppers, cockroaches or meal-worms. The sporozoites penetrate the epithelial cells of the intestinal wall and the trophozoites which develop from them are at first intra-cellular; later the trophozoites break out of the epithelial cell to which they are attached for a time by the head or epimerite (Figure 44a); this, the cephalont stage, consists of two parts, the posterior deutomerite which contains the nucleus, and an anterior protomerite and epimerite. When the cephalont becomes detached from the cell it loses its epimerite and is then known as a sporont (Figure 44b). The sporonts within the intestine unite end to end, a condition known as syzygy (Figure 44c). Two sporonts conjugate and surround themselves with a wall thus forming a cyst (Figure 44d); they are gametocytes, each of which produces a large number of gametes. The gametes copulate in pairs, thus becoming zygotes, and secrete sporocysts and hence are spores (Figure 44e). Within each spore eight sporozoites are produced. The sporozoites that are liberated in the intestine of the hosts that have ingested the spores bring about new infections.

3. SCHIZOGREGARINES

These are principally intestinal parasites of arthropods and annelid worms. As noted above, asexual reproduction or schizogony occurs in the life-cycle of the members of this group. Sometimes several types of schizonts occur in the life-cycle of a single species. Considerable variation exists in the various life-cycles in the method of formation of gametes and spores. Since the schizogregarines are not easy to obtain for study a detailed account is omitted here.

CHAPTER IX

COCCIDIA

I. *General Characteristics*

The coccidia are sporozoa whose life-cycle includes both schizogony and sporogony and is passed in a single host. They are parasitic in vertebrates, myriapods, mollusks, insects, annelids and flatworms. The life-cycle of *Isospora felis* (Figure 46) that occurs in the cat and dog has already been described (page 121). The life-cycles of other species resemble this but differ in certain respects. For example, the oöcysts of the genus *Eimeria* contain four spores, each with two sporozoites (Figure 45d); a species known as *Caryotropha mesnili,* that lives in the body cavity of an annelid, has about twenty spores in its oöcysts, each of which produces twelve sporozoites; *Cyclospora caryolytica,* which parasitizes the nuclei of the intestinal epithelium of the mole, produces oöcysts in which two spores are formed each with two sporozoites; and other variations occur in the different species.

II. *Coccidia in Man*

A number of species of coccidia have been reported from man but only one of these, *Isospora hominis,* has been definitely established as a human parasite. Several coccidia reported by Dobell (1919) as new species from man, namely, *Eimeria wenyoni* and *E. oxyspora* (Figure 45e) and a third species, named by Dobell (1921) *E. snijdersi,* have since been proved by Thomson and Robertson (1926a, 1926b) to be parasites of fish, the oöcysts of which had been eaten by the human host, had passed through the intestine and been found in the feces.

1. MORPHOLOGY AND LIFE-CYCLE OF ISOSPORA HOMINIS

This species is known only in the oöcyst stage (Figure 45 a, b). The oöcysts which pass out in the feces of the host measure from

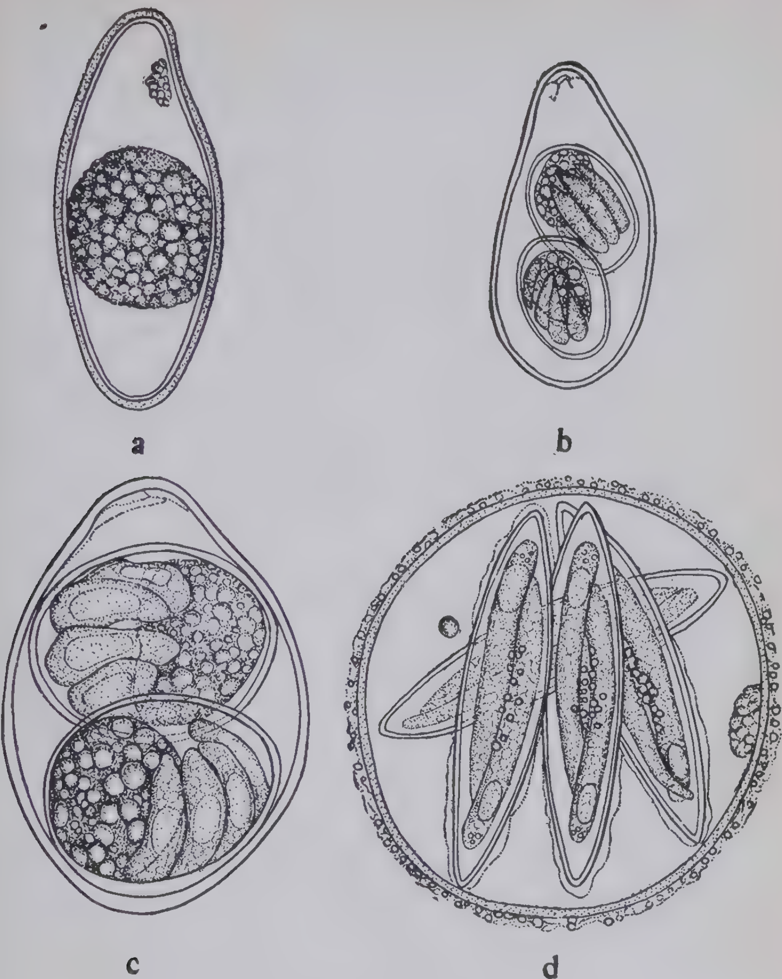


FIG. 45.—Oöcysts of Coccidia (x 1600). (After Dobell)
a. *Isospora hominis* of man, before spore formation.
b. *Isospora hominis* of man, containing two spores each with four sporozoites and a residuum.
c. *Isospora bigemina* of the cat.
d. *Eimeria sardinæ* (= *E. oxyspora*) of fish.

25 μ to 33 μ in length and from 12.5 μ to 16 μ in breadth. Their protoplasmic contents are usually in the form of a ball when they emerge in the feces. During the life outside of the body of the host the nucleus divides and the protoplasm separates into two uninucleate

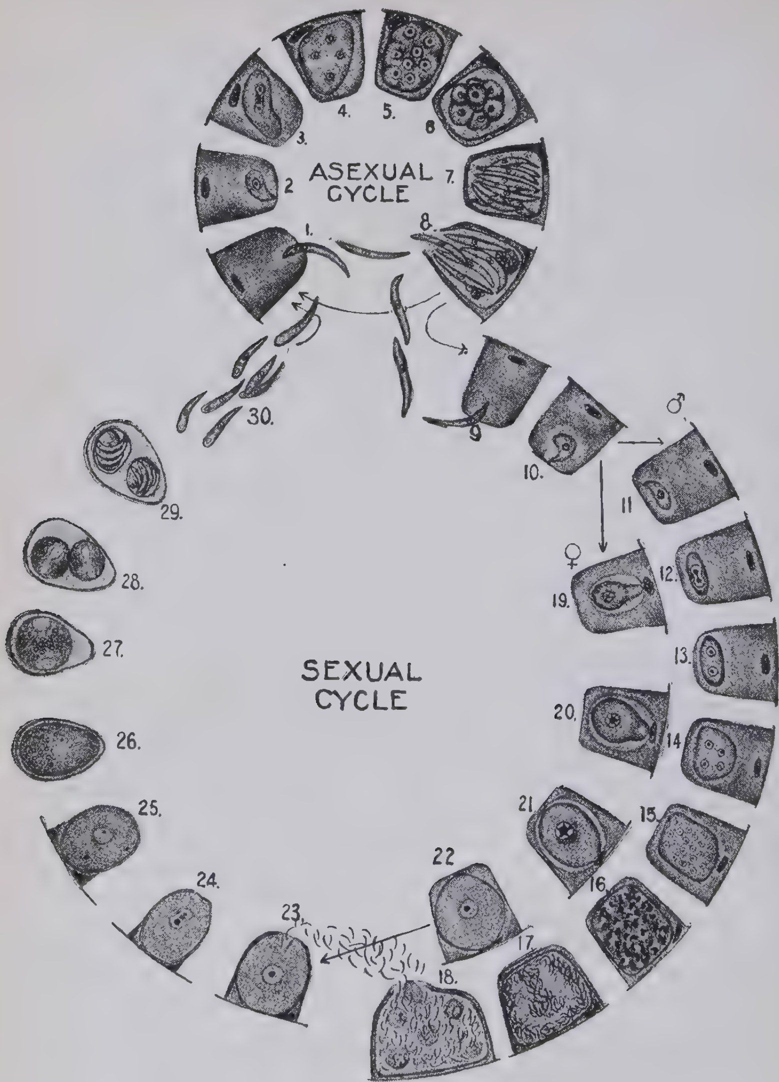


FIG. 46.—*Isospora felis*, life-cycle. (From Hegner. After Andrews) Stages 26, 27, 28 and 29 are oöcysts which pass out of the body with the feces; in each oöcyst two sporoblasts are formed (28) and in each sporoblast four sporozoites (29). When ingested by a susceptible animal the sporozoites escape from the oöcyst (30), enter epithelial cells (1) where they undergo schizogony (2-8). The merozoites produced may repeat the asexual cycle (8 to 1 to 8) or initiate the sexual cycle (9-25). In the latter, female cells (♀) or macrogametes (19-22) and male cells (♂) or microgametes (11-18) develop. Fertilization (23) is followed by the formation of the oöcyst (24-26).

sporoblasts. Each sporoblast secretes two walls (sporocysts) about itself thus becoming a spore. Within each spore four uninucleate sausage-shaped sporozoites are formed. Part of the protoplasm is not included in the sporozoite but remains behind as a residue; such a residue also occurs in certain other coccidia. The asexual cycle and sexual phenomena are not known in *Isospora hominis,* but are probably similar to those of *Isospora felis* in the cat, which are illustrated in Figure 46 and described on page 128.

2. HOST-PARASITE RELATIONS OF ISOSPORA HOMINIS

Human coccidiosis is apparently rare, only about two hundred cases having been reported. The reasons for this low incidence are not known with certainty, but it is probable that cases are frequently overlooked because the cysts do not appear in the feces until the symptoms have disappeared. Also, only a small number of oöcysts are passed by the human host. It is even possible that *I. hominis* may be a natural parasite of some lower animal and only occasionally infects man.

The oöcysts of coccidia are very resistant to factors in the external environment. Haughwout (1921), for example, exposed oöcysts of *I. hominis* in the sporoblast stage to the sun for three hours every day for a week and found that at the end of this period some of them developed sporozoites when water was added. The oöcysts thus probably remain viable for long periods outside of the body and have excellent opportunities for being ingested by man in contaminated food or drink. The sporozoites probably escape from the spore and oöcyst in the small intestine, and immediately penetrate the epithelial cells; they are thus always pathogenic although probably large numbers must be ingested before symptoms are brought about. The stages within the human body are probably similar to those of *I. felis* in cats and dogs (see Figure 46).

The best account of a human infection with *Isospora hominis* is that of Connal (1922). Six days after swallowing oöcysts the patient suffered from diarrhea; oöcysts appeared in the feces twenty-two days after the diarrhea began and were present daily for the succeeding thirteen days. Coccidial infections are of particular interest because, as in this case, the incubation period (six days) is shorter than the prepatent period (twenty-eight days), whereas in most other pathogenic protozoa of man the prepatent period is shorter than the incubation period.

III. *Coccidia in Lower Animals*

The coccidia most easily obtained for study are those in the rabbit, *Eimeria stiedæ*. Oöcysts of this species may be found in the feces of a large proportion of these animals. They are in an unsegmented stage when passed but segmentation may be observed if the material is placed in a 5 per cent aqueous solution of potassium bichromate to inhibit the growth of bacteria. Segmentation into sporoblasts and the formation of sporozoites takes place in about three days.

Eimerias of other species occur in various species of mammals, birds, reptiles, amphibia and fish. All of these are pathogenic if their life-cycles are similar to that of *E. stiedæ* in the rabbit, but most of them do not injure the host very severely. *E. stiedæ* frequently brings about the death of rabbits, however, and *E. zürnii* is the cause of diarrhea in cattle, especially in Switzerland, Sweden and Denmark. The eimeria in birds, *E. avium,* is likewise lethal under certain conditions, especially when epidemics occur among young chickens.

Coccidia of the genus *Isospora* also occur in vertebrates of all classes. Cats and dogs are commonly infected with *I. felis* and *I. rivolta.* Other species occur in birds and cold-blooded vertebrates.

CHAPTER X

HÆMOSPORIDIA EXCLUSIVE OF MALARIAL PARASITES

The hæmosporidia, as the name implies, are sporozoa that live in the blood. They penetrate the blood cells of vertebrates where they pass through schizogony and go through part of their life-cycle in invertebrate hosts where sporogony occurs. The most important species are the malarial parasites of man; a consideration of these will be deferred until the next chapter.

I. *The Genus Hæmoproteus*

The members of this genus live in the endothelial cells of the blood vessels or in the red blood cells of vertebrates. The gametocytes (Figure 47a) within the red blood cells are halter-shaped and hence are often known as halteridia. Pigment granules are produced by trophozoites in the red blood cells. It was in *Hæmoproteus* that MacCallum (1898) discovered the formation of microgametes and fertilization which led to the solution of the "exflagellation" phenomena noted by previous investigators in malarial parasites of man.

The best known species of this genus is *H. columbæ,* a parasite of the common pigeon that has been reported from various parts of the world. The life-cycle of this species includes asexual reproduction in the endothelial cells of the blood vessels of the pigeon's lungs and other organs. The trophozoites in the endothelial cells grow to large size, become multinucleate and then segment into large numbers of merozoites. These penetrate red blood cells where they develop into male or female gametocytes. When infected red cells are taken into the stomach of the hippoboscid fly, *Lynchia mauræ,* the microgametocytes continue their development producing a number of filamentous microgametes which fertilize the macrogametes that have developed, one from each macrogametocyte. The zygote thus formed becomes a motile vermiculous oökinete; this penetrates the wall of the midgut where pigmented oöcysts are formed (Adie, 1915, 1924). Large numbers of sporozoites arise within the oöcysts; they eventually es-

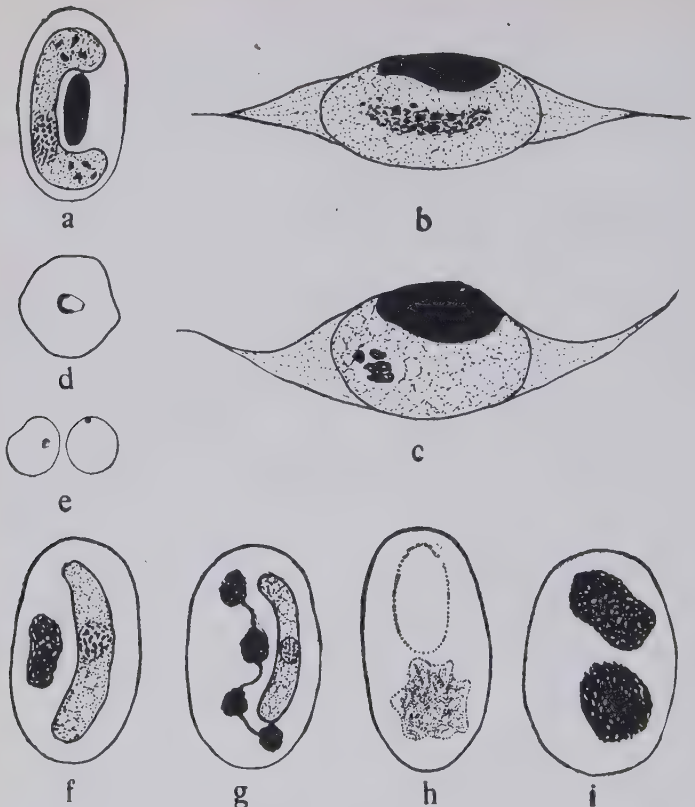


FIG. 47.—Hæmosporidia of various types.

a. *Hæmoproteus* in the red blood cell of a bird. (Original)
b, c. *Leucocytozoön* from the blood of a bird. b, microgametocyte; c, macrogametocyte. (After Wenyon)
d. *Theileria parva* in the red blood cell of a calf. (After Brumpt)
e. *Anaplasma marginale* in the red blood cells of an ox. (After Theiler)
f. *Lankesterella* in the red blood cell of a frog. (Original)
g. *Karyolysus* in the red blood cell of a frog. (Original)
h, i. *Cytamœba bacterifera* in the red blood cells of a frog. h, living; i, stained. (After Hegner)

cape and some of them reach the salivary glands where they are ready to be inoculated into the blood of any pigeon that chances to be bitten by the infected fly. This life-cycle, which requires ten to twelve days in the fly, resembles that of malarial parasites. Halteridia occur in a number of other species of birds, and in localities where flies of the genus *Lynchia* are absent, hence in these cases the invertebrate transmitting host must belong to some other species.

Halteridia of various species have been described from turtles, snakes and lizards. Very little is known, however, regarding the life-cycle and transmitting agents of these species.

II. *The Genus Leucocytozoön*

The leucocytozoa are parasites of birds, in which they occur in cells that are usually described as unpigmented and appear to be leucocytes. Hartman (1927), however, believes that the parasites contain pigment and enter young red cells. The characteristic appearance of the gametocytes is that of an oval body in a spindle-shaped cell (Figure 47 b, c). Filamentous microgametes develop from the microgametocytes and fertilize the macrogametes; the zygote thus formed becomes an oökinete. Schizogony apparently occurs in mononuclear cells in the internal organs or in the plasma and is probably similar to this process in hæmoproteus. The transmitting agents of the leucocytozoa are unknown.

III. *Hæmogregarines*

The hæmogregarines are unpigmented parasites that occur in both red and white cells in the peripheral blood. The species most easily obtained for study belong to the genera *Lankesterella* (Figure 47f) and *Karyolysus* (Figure 47,g) that occur in the blood of frogs. Other species have been reported from mammals, birds, rabbits and fish.

1. THE HÆMOGREGARINE OF RATS, HEPATOZOÖN MURIS

An excellent account of this species has been provided by Miller (1908). As shown in Figure 48, schizogony occurs in the rat and sexual phenomena and sporogony in a mite which feeds on the blood of the rat. When infected mites are eaten by a rat, sporozoites escape from the spores, penetrate the intestinal villi, enter the blood stream and are carried to the liver, where they enter the liver cells. During schizogony within these cells from twelve to twenty merozoites are produced. These may likewise enter liver cells and undergo schizogony or may break out into the blood stream, penetrate mononuclear leucocytes and develop into gametocytes. If these gametocytes are sucked up into the stomach of a mite they copulate in pairs, one member of the pair becoming a large macrogamete and the other a smaller microgamete. The zygote thus formed becomes an oökinete which

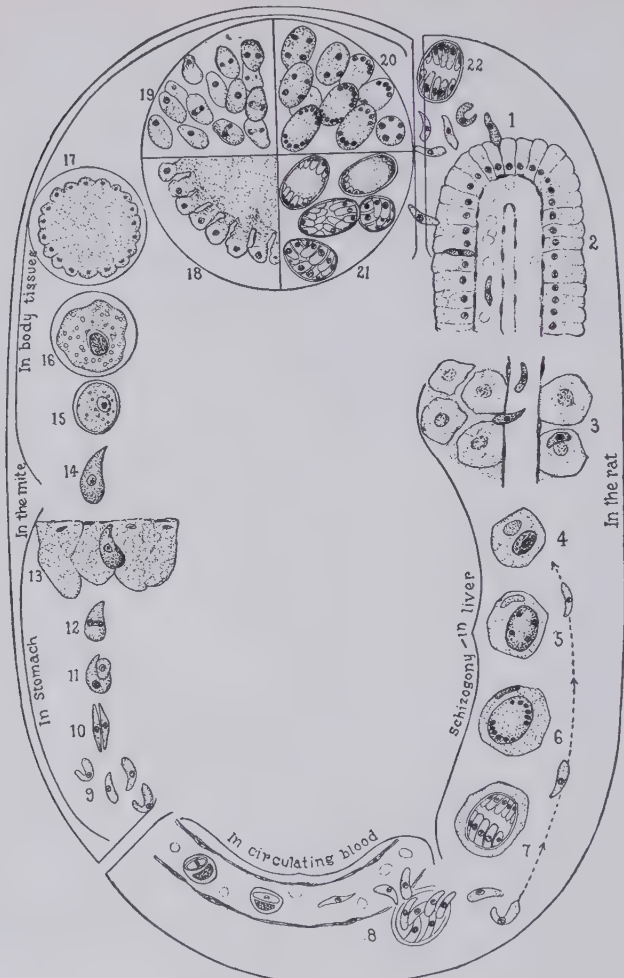


FIG. 48.—*Hepatozoön muris.* Stages in the life-cycle in the rat and the mite. (After Miller)

makes its way through the intestinal wall into the body cavity and forms an oöcyst in the tissue of the body. The oöcyst increases in size and from fifty to 100 sporoblasts are formed, each of which secretes a sporocyst and becomes a spore. About sixteen sporozoites are formed in each spore.

2. "HÆMOGREGARINES" OF MAN

At least five species of "hæmogregarines" have been described from the blood of man. Wenyon (1923, 1926) has critically examined the evidence on which these species are based and concludes that none of them can be regarded as a hæmogregarine. It cannot be stated with certainty, therefore, that hæmogregarines parasitize man.

IV. *Piroplasmidæ*

The members of this group parasitize the red blood cells of mammals and are non-pigmented. They reproduce in the red cells by division, usually into two, but sometimes into four daughter parasites. One species, *Babesia* (*Piroplasma*) *bigemina*, which causes Texas fever or red water fever in cattle, is of peculiar historical importance because this was the first protozoön whose transmission from host to host was demonstrated to be due to an arthropod; Smith and Kilbourne (1893) not only proved that *B. bigemina* is transmitted by ticks of the genus *Margaropus* (*Boöphilus*) but that so-called "hereditary" transmission takes place through the egg from the mother tick to its offspring.

1. THE GENUS BABESIA (PIROPLASMA)

Species belonging to this genus occur in cattle, sheep, goats, horses, dogs, monkeys and various game animals of the ungulate type. *B. bigemina* is the largest of several species that occur in the blood of cattle. Usually a pair of pear-shaped organisms appear in each red cell and as many as 50 per cent of the red cells may be infected in a diseased animal. Reproduction takes place within the red cell by a sort of budding process. Some of the organisms contained in the red cells are probably gametocytes. Infected animals exhibit acute or chronic symptoms; death may occur in a week or ten days or gradual recovery may ensue. Fever, anemia, jaundice and the excretion of urine colored red by the excretion of hæmoglobin by the kidneys are characteristic symptoms. Cattle that recover still carry the parasites in their blood for long periods.

Babesia canis, which is responsible for malignant jaundice in dogs in the Old World, has been more carefully studied than the other species. The parasites resemble *B. bigemina* in appearance; they are about 5 μ long and contain a nucleus from which extends a filament of fine granules and a vacuole (Figure 49,1). When division occurs, the filament becomes bifurcated at the end; then two bud-like proc-

esses appear into which the filaments extend; a vacuole arises in each bud; then the nucleus divides and finally the cell body divides and two pear-shaped daughter cells result. A flagellate form in the blood of dogs has been described.

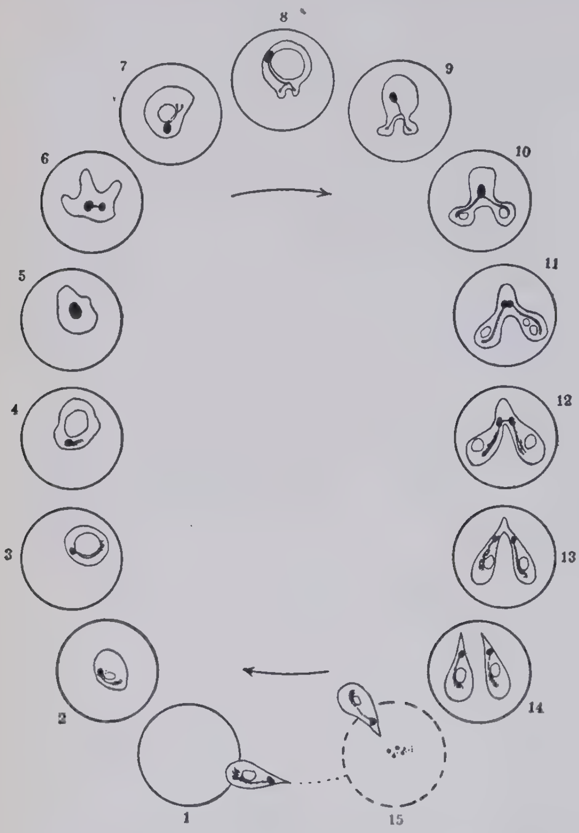


FIG. 49.—*Babesia canis.* Stages in the red blood cells of the dog. 1, parasite entering red cell. 2-5, growth within red cell. 6-13, division stages. 15, escape of daughter cells from red cell. (After Nuttall)

The cycle in the tick (*Rhipicephalus sanguineus*) has been described (Christophers, 1907) but has not been confirmed. The parasites are said to break out of the red cells in the body of the tick; they probably pass through a sexual cycle; then a club-shaped "zygote" or oökinete develops. This may enter the developing egg of the tick and become a sort of oöcyst in the embryonic tissue; growth then occurs and a number of sporoblasts are formed each of which produces many pear-shaped or irregular sporozoites which find their way into the salivary glands of the young tick.

2. THE GENUS THEILERIA

The members of this genus live in unpigmented red cells in the blood and in the endothelial cells of the capillaries in the internal

organs. They occur in cattle, the best known species being *Theileria parva* (Figure 47,d) and have been reported from sheep and goats but appear to be rare in these animals. Hayashi believes that the causative organism of tsutsugamushi disease of Japan is due to infection with a species belonging to this genus which he has named *T. tsutsugamushi.*

Theileria parva causes a disease in cattle, known as East Coast fever, that occurs in Africa and to a lesser extent in Asia. The anemia, jaundice and hæmoglobinuria, characteristic of infections with *B. bigemina,* are absent in this disease; furthermore, cattle that have recovered from infections with *B. bigemina* are not immune to *T. parva.* From 80 per cent to 90 per cent of the red cells may be parasitized in infected animals. The organisms are mostly oval or rod-shaped (Figure 47d). Schizogony, which occurs in the endothelial cells of capillaries in the lymphatic glands, spleen and other organs, results in the production of large numbers of minute merozoites which break out of the parasitized cells and either penetrate other endothelial cells and repeat the schizogonic cycle or else parasitize red cells. When an animal recovers, the organisms completely disappear from the body. *T. parva* is transmitted by ticks of the genus *Rhipicephalus.* The cycle in the tick appears to be similar to that of *B. canis* in its intermediate host.

V. *Doubtful species of Hæmosporidia*

A large number of bodies resembling protozoa have been described from the blood of man and lower animals and included in this group. Their exact nature still remains to be determined. Three genera may be mentioned here; *Toxoplasma, Cytamœba* and *Anaplasma.*

1. TOXOPLASMA

This genus was proposed (Nicolle and Manceaux, 1909) for a parasite discovered in a North African rodent. The organism is crescent shaped and from 4 μ to 6 μ in length. Reproduction is by longitudinal binary division and schizogony has also been described. Bodies supposed to represent species belonging to this genus have been reported in various species of mammals and birds and one species, *T. pyrogenes* (Castellani, 1914), has been reported from the blood and spleen of man. The exact status of these bodies is yet to be determined.

2. CYTAMŒBA

The name *Cytamœba bacterifera* was applied by Labbé (1894) to bodies that occur in the red cells of European frogs. Similar bodies occur in the red cells of *Rana clamitans* and *R. catesbiana* of North America (Hegner, 1921). They are located at one end of the red cell and, in freshly drawn blood, exhibit amœboid changes in shape (Figure 47h). After a few minutes they become spherical. Within them are many rod-shaped, actively moving bodies named *Bacillus krusei* by Laveran (1899). The nature and systematic position of these bodies are doubtful.

3. ANAPLASMA

Theiler (1910) applied the name *Anaplasma marginale* (Figure 47e) to minute spherical bodies that appear near the margin of the red cells of cattle suffering from infection with *Babesia bigemina* and considered them to be protozoa consisting entirely of chromatin. Similar bodies have been noted in the red blood cells of other animals.

CHAPTER XI

MALARIAL PARASITES OF MAN

I. *Introduction*

The three species of malarial parasites that live in man belong to the genus *Plasmodium* and to the family PLASMODIDÆ. Besides these, there are a number of other species belonging to the same genus and family that parasitize species of mammals, birds and lizards. The morphology and life-cycles of all of the different species of plasmodia are similar. There is an asexual cycle in a vertebrate host and a sexual cycle in an invertebrate vector. Malaria is the most important disease of man due to an animal parasite. It is the most important of all diseases in many tropical and semitropical countries. It must be eradicated from these localities before they can be developed, hence the economic phases of malariology are of particular interest.

II. *The Discovery of the Malarial Parasites in Man and Mosquito*

Many theories were proposed to account for the symptoms that accompany malaria before the real etiological agent was discovered by Laveran in Algeria in 1880. At the time Laveran made his discovery the attention of scientific men was largely directed toward the so-called *Bacillus malariæ* which Klebs and Tomassi-Crudeli had announced as the causative organism of malaria. Thus, although the real parasite was described in 1880, it was not until 1885 that students in general accepted Laveran's work. In that year Marchiafava and Celli gave the name *Plasmodium malariæ* to the organism of quartan malaria. The species name *vivax* was given to the tertian parasite by Grassi and Feletti in 1890 and that of *falciparum* to the estivo-autumnal parasite by Welch in 1897. Golgi, who distinguished the different types of malarial parasites, described in 1885 and 1886 the asexual cycle of the quartan parasite in the blood of man and later in that of the tertian parasite. Golgi also realized the significance of the presence of crescents in the blood and recognized the third type of malaria due to *Plasmodium falciparum*.

The discovery of the sexual cycle of malarial parasites in mosquitoes was due to the prediction by Sir Patrick Manson (1894) that malaria would be found to be transmitted by mosquitoes and to the investigations of Sir Ronald Ross. Ross did his work in India. He observed in 1895 the formation of gametes from crescents in the stomach of the mosquito, a process then known as exflagellation, the significance of which was not realized until 1897 when MacCallum proved it to be a maturation process followed by the fertilization of female gametes. Oöcysts were found by Ross in 1897 in the stomach of a mosquito that had fed on infected human blood. In the following year Ross (1898) worked out the whole life-cycle of the organism of bird malaria in culex mosquitoes. Circumstances over which he had no control prevented Ross from completing the stages of the sexual cycle of human malarial organisms in mosquitoes; this was done by Grassi, Bignami and Bastianelli (1898) in the same year, but after Ross's results on bird malaria had been published. These Italians succeeded in infecting three men by allowing infected mosquitoes to bite them, and Manson in 1900 infected a man in London by means of mosquitoes imported from Italy, thus finally demonstrating the rôle of the mosquito as the transmitting agent of malaria.

III. *The Asexual Cycle of the Malarial Parasites in Man*

I. PLASMODIUM VIVAX

The three species of human malarial organisms differ in their life-cycles in only minor details. For this reason a rather full account of the tertian parasite, *Plasmodium vivax,* will be presented, followed by briefer descriptions indicating the differences between this and the other two species.

Sporozoite. The stage in the asexual cycle that is inoculated into human beings by the bite of an infected mosquito is a sporozoite. This is spindle shaped, 10 μ to 12 μ in length and 1 μ to 2 μ in breadth, and contains an oval nucleus (Figure 50, *1*). The sporozoites apparently penetrate the red blood corpuscles by means of boring movements (Figure 51 a,b,c). Several thousand of them are probably inoculated during the bite of a mosquito but many of these are no doubt destroyed by phagocytes.

Trophozoite. Within the red cell the organism changes into an amœboid hyaline body known as a trophozoite (Figure 50, *2*). This throws out pseudopodia actively, hence the specific name *vivax*. The trophozoite grows at the expense of the cytoplasm in the corpuscle

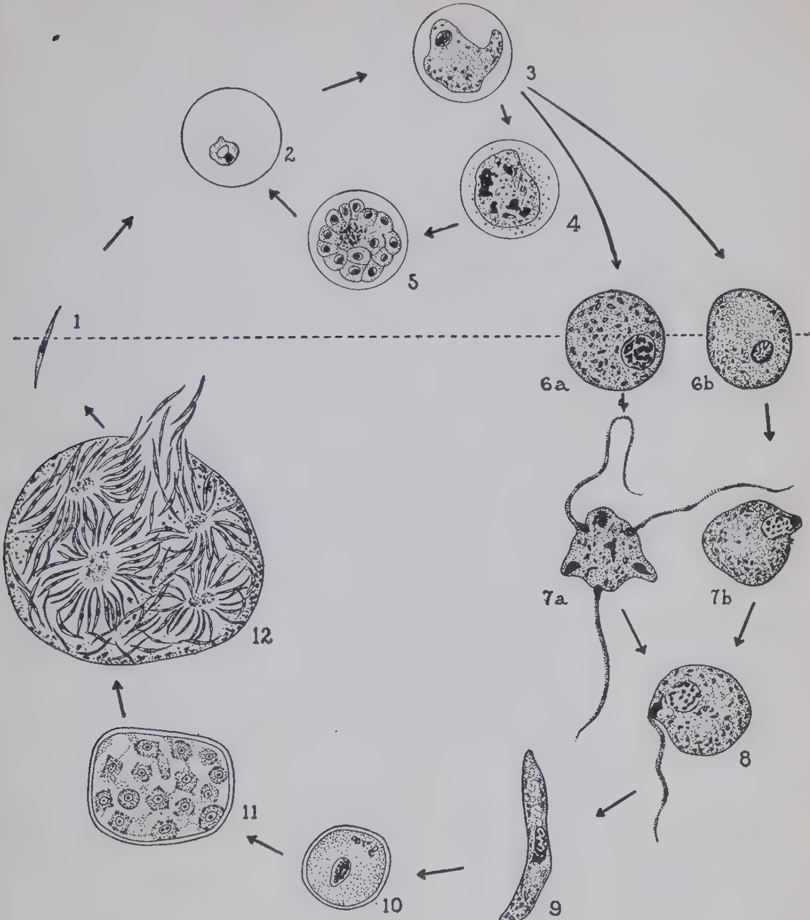


Fig. 50.—Life-cycle of the tertian malarial parasite, *Plasmodium vivax*. The stages above the dotted line occur in the peripheral blood of man, whereas those below are found only in the mosquito. 1, Sporozoite. 2, Trophozoite, in red cell. 3, Full-grown schizont. 4, Schizont with chromatin in several masses. 5, Segmentation stage. 6a, Male gametocyte. 6b, Female gametocyte. 7a, Exflagellation of male gametocyte—formation of microgametes. 7b, Female gametocyte extruding chromatin from nucleus. 8, Fertilization of macrogamete by microgamete. 9, Oökinete. 10, Young oöcyst. 11, Oöcyst with many nuclei. 12, Ripe oöcyst discharging sporozoites. (After Hegner and Cort)

and as it becomes larger the infected cell increases in size (Figure 52, A*2*). Pigment granules, which represent the by-products of the digestion of hæmoglobin, appear within the parasite in about six to eight hours. When stained by the Romanowsky method the cytoplasm

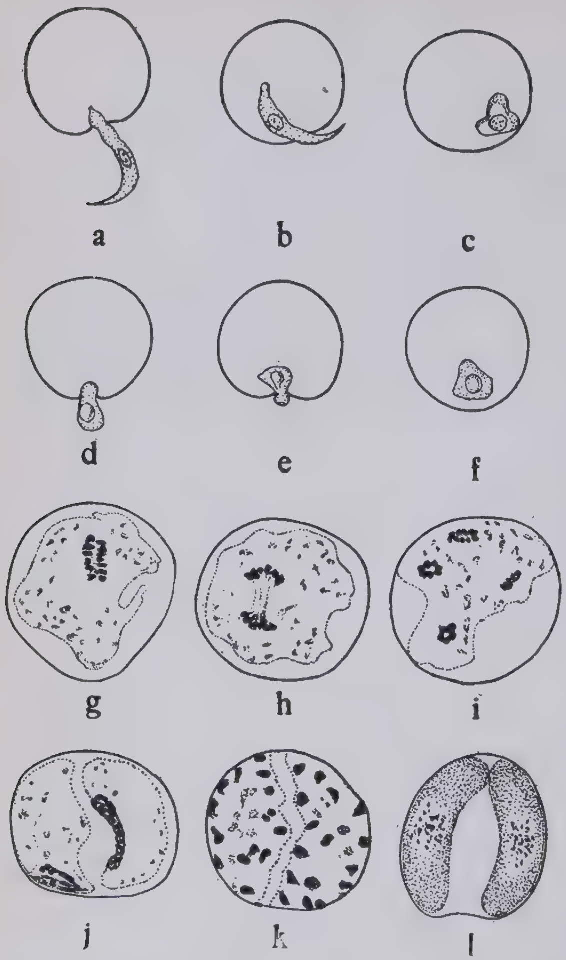


FIG. 51.—Malarial parasites of man. (a-i, after Schaudinn; j, k, after Thomson and Woodcock; 1, after Manson-Bahr)

a, b, c. Sporozoite penetrating a red cell.
d, e, f. Trophozoite penetrating a red cell.
g, h, i. Schizont undergoing nuclear division.
j. Two macrogametocytes in a single red cell.
k. Two schizonts, ready to segment, in a single red cell.
l. Two gametocytes (crescents) in a single red cell.

of the trophozoite is blue and the chromatin of the nucleus red. The latter usually lies at one side of a vacuole which gives the young trophozoite a ring-like appearance (Figure 52, A1). Older trophozoites are amœboid in shape and when fully grown at the end of forty hours, practically fill the enlarged red cell (Figure 50, 2). Degeneration spots in the protoplasm of the parasitized cell may appear as bright pink dots known as Schüffner's dots (Figure 50, 4; Figure 52, A2); these are not always present, probably because of idiosyncrasies in staining. A single red cell may be parasitized by more than one trophozoite, especially when large numbers are present (Figure 51 j, k, l).

Schizogony. A trophozoite may become a sexual stage, a gametocyte, or an asexual stage, a schizont. The full-grown schizont is 8 μ to 10 μ in diameter (Figure 50, 3). Its nucleus, by successive divi-

sions (Figure 51 g, h, i), produces from fifteen to twenty-four daughter nuclei. Each daughter nucleus with a portion of the cytoplasm is then cut off as a minute cell known as a merozoite, and the pigment granules become aggregated near the center of the schizont (Figure 50, 5; Figure 52, A3). Then the infected red cell breaks down, liberating the merozoites, pigment granules and the remains of the red cell into the blood stream. It is probable that toxins elaborated by the parasite are also liberated at this time and are responsible for the symptoms of chills and fever.

The liberated merozoites penetrate fresh red corpuscles (Figure 51 e, f, g) and repeat the asexual cycle, which requires a period of forty-eight hours. The pigment granules are engulfed by leucocytes and carried to the internal organs, especially the spleen, liver and brain. Asexual reproduction continues as long as a host is parasitized, and, when a sufficient number of parasites are present, a number estimated by Ross (1911) as 150,000,000, symptoms are exhibited by the patient.

Whether the trophozoite is within or attached to the outside of the red blood corpuscle is a problem that has been under discussion for many years. Most observers believe that the parasite penetrates and lives within the red cell, but others, especialy Lawson (1911-1920), Sinton (1922) and DeLangen (1925), believe that their studies show the parasite to be attached to the outside. The recent work of Ratcliffe (1927) involving the fixation and sectioning of infected blood of both man and bird seems to prove conclusively that the malarial organism is intracellular and not extracellular.

The penetration of a single red cell (Figure 51 j, k, l) by two or more parasites is not as common in the case of *Plasmodium vivax* as in that of *P. falciparum* where it occurs so frequently as to be of diagnostic value. Double or triple infections with *P. vivax* are also frequent; that is, two or three groups of parasites may live in a single host at the same time, undergoing schizogony on different days and thus bringing on symptoms at more frequent intervals than usual.

Gametocytes. Some of the parasites that penetrate the red blood cells do not undergo schizogony, but develop into sexual stages known as gametocytes (Figure 50, 6a, 6b; Figure 52, A4). These are unable to develop into gametes in the body of the vertebrate host, but degenerate in time if they are not sucked up into the stomach of a mosquito. Gametocytes usually appear in the blood after several generations of merozoites have been produced. They may be distinguished from schizonts, and macrogametocytes and microgameto-

cytes may be separated on the basis of morphology. The macrogametocytes are from 13 μ to 16 μ in diameter; the cytoplasm stains a dark blue; the chromatin consists of a small compact mass excentrically placed and the pigment consists of long rods. The microgametocytes are 9 μ to 11 μ in diameter; the cytoplasm stains light blue; the chromatin consists of a large diffuse mass centrally located; and the pigment is in small rods.

2. PLASMODIUM MALARIÆ

The asexual cycle of *Plasmodium malariæ,* the organism of quartan malaria, differs from that of *P. vivax* in the following respects. The entire period from the penetration of the red cell to the liberation of merozoites is seventy-two instead of forty-eight hours. The infected red cell is approximately normal in size and no degeneration spots such as Schüffner's dots appear (Figure 52, B). The schizont is small and so frequently quadrilateral in shape as to be of diagnostic importance (Figure 52, B2). Pigment occurs within the organism in the form of large irregular granules. The merozoites number from six to twelve; they are often arranged in a single rosette with the pigment granules in the center (Figure 52, B3). The gametocytes are similar in appearance to those of *P. vivax* but much smaller (Figure 52, B4). As in *P. vivax,* one red cell may contain several parasites, but this is comparatively rare. Also one host may be infected with two or more groups of parasites, due to inoculation by mosquitoes on different days; hence clinical symptoms may appear at shorter intervals than seventy-two hours. Apparently there is no antagonism between groups of parasites belonging to the same species or to different species, since a single host may be infected with *P. vivax* and *P. malariæ* at the same time.

3. PLASMODIUM FALCIPARUM

P. falciparum, the organism of estivo-autumnal malaria, has an asexual cycle of from twenty-four to forty-eight hours. It is believed by some (Craig, 1921) that two distinct varieties of *P. falciparum* exist differing in the length of the asexual cycle. The size of red cells infected with *P. falciparum* is approximately normal (Figure 52, C). Spots known as Maurer's dots, which stain a brick red, may be present in the cytoplasm of the infected cells (Figure 52, C2). The schizont is small and more or less circular in outline. The pigment granules are smaller than those of *P. malariæ* and irregular in

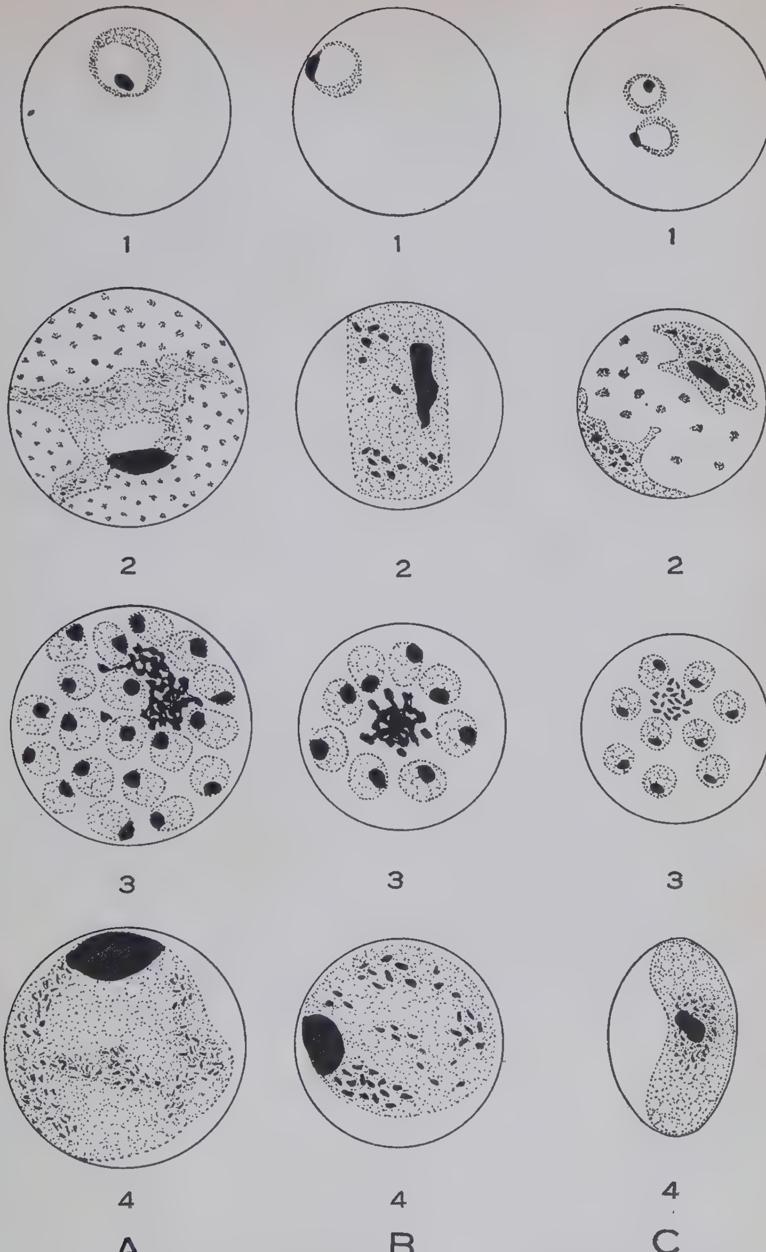
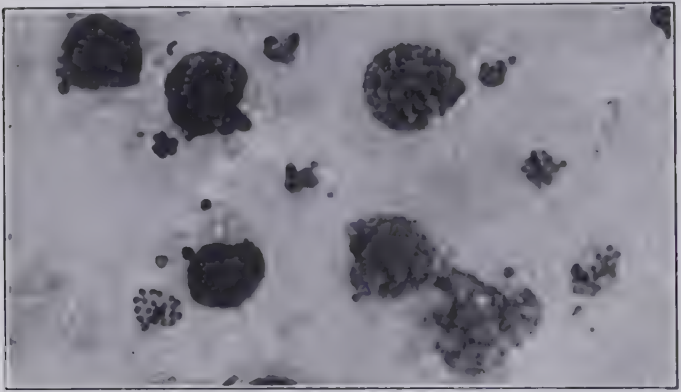


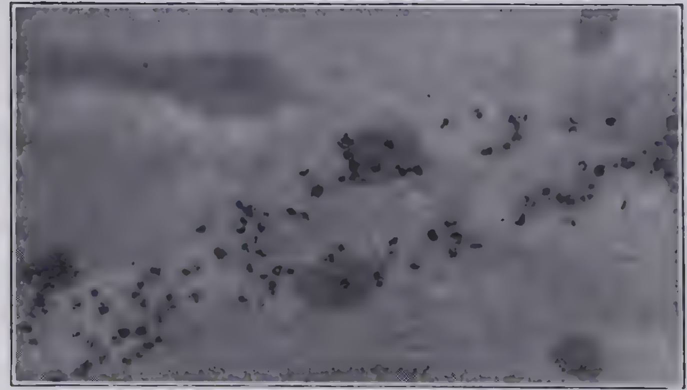
FIG. 52.—Four stages in the life-cycle of each of the three malarial parasites of man illustrating characteristics of diagnostic importance. (After Hegner and Cort)

A. *Plasmodium vivax.* 1, Ring stage; 2, schizont; 3, segmenter; 4, gametocyte.
B. *P. malariæ.* 1, Ring stage; 2, schizont; 3, segmenter; 4, gametocyte.
C. *P. falciparum.* 1, Ring stage; 2, schizont; 3, segmenter; 4, gametocyte.

shape. Schizogony occurs almost entirely in the capillaries of internal organs (Figure 53 a) and segmenting parasites are not numerous in the peripheral blood. From eight to ten or more merozoites are pro-



a



b

FIG. 53.—a. *Plasmodium falciparum,* segmenting schizonts in placental blood. (Photograph from Taliaferro)
b. *P. falciparum,* parasites in capillary of the brain. (Photograph from Clark)

duced by a single parasite (Figure 52, C3). These are very small and are arranged irregularly or in the form of two rings. Frequently a single cell is parasitized by two or more merozoites (Figure 52, C2). Often parasites in the ring stage are located at the very edge of the corpuscle with the chromatin mass apparently protruding

(Figure 52, C 2). The chromatin in many cases is divided into two bodies. The gametocytes of *P. falciparum* are very distinctive, being crescentic in shape instead of ovoidal or spherical (Figure 52, C4; Figure 51, *l*). The macrogametocytes are cylindrical; the cytoplasm stains a deep blue and the chromatin forms a single mass in the center surrounded by a compact circle of pigment granules. The microgametocytes are broad; the cytoplasm stains a lighter blue and the chromatin and pigment granules are scattered irregularly throughout the central region of the gametocyte. A single host may be infected with all three species of malarial parasites or with any two of them.

IV. *The Sexual Cycle of the Malarial Parasites in the Mosquito*

1. GAMETOGENESIS

As stated above, gametocytes cannot complete their development in the blood of the vertebrate host. In drawn blood or in the stomach of a mosquito gamete formation occurs if the gametocytes are ripe. First, as in higher organisms, a process of maturation is supposed to occur during which part of the chromatin is cast out in the form of polar bodies (Figure 50, *7b*). The gametocytes then escape from the red cell by the bursting of the cell wall, the product of the macrogametocyte being a single microgamete and that of the microgamete being a body from which six to eight whip-like processes grow out (Figure 50, *7a*); these eventually break away from a residual mass of protoplasm as microgametes. This process was known for many years as exflagellation.

2. FERTILIZATION

The active microgametes swim about until they encounter a passive macrogamete. Each of the latter is fertilized by a single microgamete which fuses with it (Figure 50, *8*). Since macrogametes are unable to develop without fertilization, it is obvious that blood is not infective to mosquitoes unless it contains both macrogametocytes and microgametocytes. Furthermore, these must be ripe. It is thus evident that hosts in whose blood only one type of gametocyte exists are not dangerous as reservoirs of infection. Cases are on record of such hosts. As is pointed out in Section III of this book, only a comparatively few species of mosquitoes of the genus *Anopheles* are capable of transmitting malaria. Huff (1927) has shown that fer-

tilization occurs in mosquitoes that do not transmit malaria but that the later stages of the sexual cycle do not occur.

3. SPOROGONY

The zygote, which results from the fusion of a microgamete with a macrogamete, soon becomes elongated and active and is then known as an oökinete (Figure 50, *9*). The oökinete makes its way to the stomach wall by gliding movements resembling those of gregarines, penetrates the tissues and becomes located between the outer epithelial layer and the muscular layers of the stomach wall. Here it becomes a spherical oöcyst (Figure 50, *10*). The period from the ingestion by the mosquito to the oöcyst stage requires about forty hours. The oöcyst obtains nutrition from the tissue in which it lies and grows from an original size of from 12 μ to 14 μ in diameter to 50 μ to 60 μ in diameter. There may be as many as five hundred oöcysts in the stomach wall of a single mosquito.

The nucleus of the fully grown oöcyst produces by successive divisions from twenty to thirty daughter nuclei; then vacuoles appear which eventually become connected in such a way as to divide the cytoplasm into irregular masses (Figure 50, *11*). Projections grow out from these masses which become spindle shaped and in each of which is a nucleus; thus the sporozoites are developed (Figure 50, *12*). It requires four or five days for the fully grown oöcyst to produce sporozoites. From several hundred to as many as ten thousand sporozoites may develop within a single oöcyst.

Eventually the oöcyst bursts and the sporozoites are liberated into the body cavity. They are carried about in the blood stream to all parts of the body, many of them finding their way into the salivary glands where they lie ready to be injected into the next human being bitten by the mosquito.

The sexual cycle of the three species of malarial parasites of man are similar in most respects. Different species of mosquitoes, however, differ with regard to their susceptibility to infection with the different species of parasites. The parasites differ also in the length of the period from the time gametocytes are ingested by the mosquito to the liberation of the sporozoite. The optimum temperature for the development of the three species within the mosquito also differs. For example, *Plasmodium vivax* passes through its sexual cycle in eight or nine days at 25°C. to 30°C., *P. malariæ* in from eighteen to twenty-one days at 22°C., and *P. falciparum* in ten to twelve days at 30°C.

TABLE III.

V. *Differential Diagnosis of Human Malarial Parasites (Stained Preparations)*

Species	*Plasmodium vivax*	*Plasmodium malariæ*	*Plasmodium falciparum*
Type of Fever	Tertian (benign tertian)	Quartan	Malignant tertian (Estivo-Autumnal, Subtertian)
Length of asexual cycle in man	48 hours	72 hours	24-48 hours
Size of infected cell	Greater than normal	Approximately normal	Approximately normal
Dots in infected cell	Schüffner's dots	None	Maurer's dots
Shape of schizont	Circular in outline	Quadrilateral	Circular
Size of schizont	Large	Intermediate	Small
Size and shape of pigment granules	Short rods	Large, irregular	Smaller, irregular
Number of merozoites	15 to 24	6 to 12	8 to 10 or more
Arrangement of merozoites	Two rings or irregular	One ring, a rosette	Two rings or irregular
Shape of gametocytes	Ovoidal or spherical	Ovoidal or spherical	Crescentic

VI. *Host-Parasite Relations*

1. TRANSMISSION

The malarial parasites of man are transmitted in nature only by certain species of mosquitoes belonging to the genus *Anopheles* (see Section III). Apparently lower animals, with the possible exception of certain monkeys, cannot be infected with human malarial parasites (Bass, 1922), hence there are no animal reservoirs of these organisms, and mosquitoes can only become infected by ingesting blood from parasitized human beings.

2. PARASITOLOGICAL AND CLINICAL PERIODS

The prepatent period in a malarial infection depends on the method of study. Ross (1911) has estimated that if 150,000,000 parasites are present in an average human being it would require from ten to fifteen minutes to find a specimen in a thin film. If one thousand sporozoites are inoculated by a mosquito, and ten merozoites from each segmenting schizont succeed in infecting fresh red cells at the end of each asexual cycle, it would require twelve days to produce as many as 150,000,000 parasites; twelve days may thus be considered the length of the prepatent period, although this period obviously would be shorter if a larger number of sporozoites were inoculated by a mosquito, and longer in the case of *P. malariæ* than in *P. vivax* because the asexual cycle in *P. malariæ* occupies a greater length of time. The length of the patent period varies greatly depending on many factors, including the physiological condition of the host and whether or not treatment is given. Usually parasites eventually become so few in number that they are very difficult to find during the subpatent period, but the host is subject to other patent periods at intervals which correspond to periods of relapse. A host once infected may remain infected for many years.

The incubation period of tertian malaria is from fourteen to eighteen days, of quartan malaria from eighteen to twenty-one days, and of estivo-autumnal malaria from nine to twelve days. As noted above, symptoms appear when about 150,000,000 parasites are present and continue for periods that vary in length in different individuals. If the patient recovers with or without the aid of a therapeutic agent, a latent period ensues to be followed frequently by one or more periods of relapse.

3. DISTRIBUTION AND LOCALIZATION WITHIN THE HOST

The malarial organisms are primarily intracellular parasites although they are free in the blood in the sporozoite and merozoite stages, and in the body of the mosquito during part of the sexual cycle. They are distributed throughout the human body in the blood stream and are as abundant in the blood vessels of the internal organs as in those of the peripheral circulation. *P. falciparum* is peculiar in that the segmenting stages are, for some unknown reason, retained in the internal organs (Figure 53 a). They are especially abundant in the spleen, liver, brain, bone marrow and placenta.

4. SYMPTOMS

One of the most conspicuous characteristics of malaria is its periodicity. The most prominent symptoms are chills and fever occurring every twenty-four, forty-eight, or seventy-two hours, depending on the species. The typical paroxysm consists of a chill, during which the skin is cold, the pulse weak and the lips blue, a rise in temperature accompanied by hot, dry skin, flushed face, strong pulse and thirst, and a decrease in temperature which is the sweating stage, and ends in apparent recovery. After a series of attacks with high temperature, the temperature at each attack becomes lower until symptoms cease.

5. PATHOLOGY

Three of the primary characteristics of malaria are pathological in nature. These are the deposition of pigment in the tissues, enlargement of the spleen and anemia. The last named condition is due to the destruction of red blood cells during schizogony and possibly to the production by the parasites of a hæmolytic agent. There is a reduction in hæmoglobin corresponding to that of the red cells. The pigment granules, which escape when the parasitized red cells break down, are engulfed by leucocytes and distributed throughout the body, but especially to the spleen, liver, brain and bone marrow. This pigment occurs in no other disease. The enlargement of the spleen in human beings infected with malarial organisms is a characteristic of diagnostic value since the disease and its severity may often be judged by the extent of its enlargement. The swelling is due to distention with blood as a result of lowered vascular tone. The spleen filters out pigment and the remains of infected red cells.

The liver also commonly becomes enlarged during an attack of malaria. In infections with *P. falciparum* there is a mechanical massing of parasites and pigment in the capillaries of the cerebrum and other organs (Figure 53 b).

6. IMMUNITY

Immunity to malaria may apparently be acquired by frequent infection and reinfection but the degree of immunity is comparatively slight. In highly malarious countries children become infected and exhibit symptoms but those who survive and reach the age of about ten years, although still infected, do not exhibit symptoms. Immunity of this type can also be established in adults by frequent inoculation with blood containing *P. vivax,* the degree of immunity acquired varying directly with the number of inoculations and the strain of parasite used. Results of this sort have been obtained in experiments on the effects of malaria on patients suffering from general paralysis.

7. LATENCY, RELAPSE AND THE CARRIER CONDITION

Latency. We may distinguish two types of latency in malarial infections, primary latency, which is often simply an extended period of incubation, and secondary latency, which represents the periods between relapses. The period of primary latency may extend over months or even years, the parasites, because of lack of virulence or a natural resistance of the host, being unable to increase in numbers sufficiently to bring about symptoms. During periods of secondary latency, a few parasites remain in the body, where they continue to reproduce asexually, but appear to be destroyed in large numbers by the resistance of the host. Both types of latency may end as a result of a change in climate or exposure to cold, inebriation and other factors that tend to lower resistance. In some cases infected persons show slight symptoms but are able to be about; they are said to be suffering from ambulatory malaria.

Relapse. As indicated in the diagram (page 14) latent periods are ordinarily followed by periods of relapse. Relapses occur in all three types of human malaria, often in from one to three weeks after the end of the primary attack. Over half of the patients suffering from quartan malaria experience relapses, slightly less than half of the patients suffering from tertian malaria and about one fourth

of those with estivo-autumnal malaria. Longer periods of latency, sometimes called recurrences, are characteristic later in the course of the disease. These range from a few months to a year or more.

There are a number of theories to account for relapse but the one that seems to be correct is that asexual reproduction occurs during the latent periods at the same rate as during the incubation period and period of symptoms, but that the resistance of the host is sufficient to destroy most of the parasites but not all of them. Relapse is of great importance in the control of malaria since in many regions mosquitoes do not remain infected throughout the winter season but become reinfected in the spring from persons suffering from relapse who have large numbers of gametocytes in their blood. If all of the parasites could be eliminated from the human host there would be no reservoir from which the mosquito could become infected and malaria would, therefore cease to exist in certain localities.

Carriers. Two types of carriers may be recognized among human beings infected with malaria. Potential carriers are those in whose blood parasites occur in such small numbers as to be non-infective to mosquitoes. Active carriers, on the other hand, have a sufficient number of ripe gametocytes of both sexes to bring about infection in mosquitoes. The number of carriers in a malaria district is indicated by the figures obtained by Bass (1919), who found in Bolivar County, Mississippi, during 1916 to 1917, 6,664, out of 31,459 persons examined, to be infected. About 45 per cent of those infected had no symptoms when examined and had had no symptoms during the previous year. Apparently at least twelve gametocytes (estivo-autumnal) must be present in each cubic millimeter of blood before a mosquito becomes infected (Darling, 1910). A carrier in whose blood there are few gametocytes is consequently not as infective to mosquitoes as one containing large numbers of gametocytes.

VII. *Treatment, Prevention and Control*

1. TREATMENT

Two therapeutic agents are of particular importance in the treatment of malaria. The better known of these is quinine, which is derived from the bark of a tree, and the curative powers of which were discovered by the Indians of Peru and became known to the Spaniards about 1600. Quinine may be administered by mouth, by intravenous injection or by intramuscular injection. It is quickly absorbed into the blood but its method of destroying the malarial

parasites is not known with certainty; it may kill the parasite directly or act through the body of the host.

The second therapeutic agent, known as plasmochin, was recently discovered and the practicability of its use has not been fully determined (Mühlens, 1926; Hegner and Manwell, 1927). Plasmochin appears to be particularly destructive to gametocytes and less injurious to the young trophozoites than quinine. A combination in the form of sugar-coated pills containing 0.01 gram of plasmochin, and 0.125 gram of quinine sulphate, called "plasmochin compositum" has been found to be particularly valuable since the plasmochin destroys the large schizonts and gametocytes and the quinine attacks the younger stages.

2. PREVENTION AND CONTROL

Malaria depends for its existence on the presence of (1) certain species of mosquitoes and (2) human gametocyte carriers. Individuals may protect themselves from infection by screening the houses in which they sleep or in other ways preventing infected mosquitoes from biting them. Prophylactic doses of quinine or plasmochin may prevent infection or prevent the appearance of symptoms even if parasites are inoculated by mosquitoes. Communities may be protected either by antimosquito measures (see Section III), or by the elimination of human carriers. The latter involves attacks on the parasite in the body of the host. The use of quinine has been to some degree effective in several parts of the world in sterilizing carriers and plasmochin will no doubt be of use in this connection.

However, there are many difficulties involved in the sterilization of malaria carriers. Our methods of detecting the carrier condition are not entirely satisfactory; carriers when once detected are not always willing to take the proper treatment, and no treatment has yet been devised that will eliminate all of the parasites from the body with certainty. What is needed more than anything else is a therapeutic agent that will destroy *all* of the parasites in the human host and thus prevent the carrier condition.

VIII. *Therapeutic Malaria*

No account of the malarial parasites of man would be complete without at least a brief statement of their use in therapeutics. Wagner von Jauregg of Vienna, in 1887, suggested the use of malaria for treating general paralysis, but it was not until 1917 that he actually

inoculated nine patients suffering from this disease with blood containing *Plasmodium vivax*. The favorable results obtained led to further inoculations in 1919. Since then many hospitals in various parts of the world have introduced malaria treatment with considerable success. The patient is infected and allowed to pass through from five to twelve febrile attacks. He is then treated with quinine. A number of theories have been proposed to account for the beneficial effects of the malarial infection, such as the injurious effects of high temperature on the spirochætes that cause general paralysis, and the formation of antibodies due to the presence of the malarial organisms that are destructive to the spirochætes, but which theory, if any, is correct is not known (see Rudolf, 1927). Many new facts regarding malaria in man have been secured as a result of the study of therapeutic malaria, since the exact time when the patient becomes infected can be controlled and various other factors determined.

IX. *Methods of Obtaining and Preparing Malarial Parasites for Study*

1. LIVING SPECIMENS

If fresh blood from a patient suffering from malaria is placed under a cover-glass and examined at once with a compound microscope the parasites can be seen within the red cells. The older stages, can be detected because of the presence of pigment granules, which are reddish brown in color, are actively motile in *P. vivax*, slightly motile in *P. malariæ*, and feebly motile in *P. falciparum*. Living trophozoites can be seen to throw out pseudopodia, those of *P. vivax* and *P. falciparum* being more actively amœboid than those of *P. malariæ*. If blood containing considerable numbers of gametocytes is examined under a cover-glass the formation of microgametes may occur within a few minutes, followed by the process of fertilization and the change of the spherical zygote into a vermicular oökinete.

2. CULTIVATION

Malarial organisms were first cultivated *in vitro* by Bass (1911) and Bass and Johns (1912). Blood containing malarial organisms was defibrinated and 0.1 c.c. of a 50 per cent solution of dextrose added to each 10 c.c. of blood. The mixture was placed in test-tubes and incubated at 40° C. Subcultures were made by centrifuging the cultures so as to throw the red cells to

the bottom, thus freeing them from the leucocytes, and transferring the red cells to fresh culture tubes. Three asexual generations were obtained in this way by Bass and Johns. More refined methods of cultivation have been described by Row (1917) and Sinton (1922) but very little has been added to our knowledge of malaria by this means.

3. STAINED SPECIMENS

Malarial organisms are usually studied in blood films dried on slides and stained with Romanowsky stain. Films are of two types, thin and thick. Thin films are made as follows: the ear lobe or end of the finger is punctured with a Hagedorn needle and a drop of blood obtained one half inch from the end of a slide. Another slide is at once applied to this drop and drawn along, thus spreading the blood out into a thin film. This is then allowed to dry. If Wright's or Leishman's stain is used the film is covered with a few drops of stain and one minute later double the volume of distilled water is added; five minutes later this is washed off and the film is dried in the air. The cytoplasm of the parasite is stained blue and the chromatin red by this method. The pigment remains unstained. If Giemsa's stain is used the film is fixed in absolute methyl alcohol for five minutes; washed gently; and then one part of Giemsa plus ten parts of distilled water added for ten minutes. When washed and dried the parasites are stained as in Wright's or Leishman's stains.

Thick films are of value especially in detecting the presence of parasites, but the species of parasite is more difficult to determine than in thin films. Four drops of blood are obtained near the center of a slide and spread over an area of about one half of a square inch. When dried it is decolorized in 95 per cent alcohol, plus 2 per cent HCl for thirty minutes; washed for a few minutes and then stained with Wright's stain as described above. This method concentrates the parasites in a small area and hence a shorter length of time is required to find a specimen.

CHAPTER XII

MALARIAL PARASITES OF LOWER ANIMALS

I. *Malarial Parasites of Monkeys*

Malarial parasites were first detected in monkeys by Koch in 1898 and named *Plasmodium kochi* by Laveran in 1899. Since then at least seven more new specific names have been applied to malarial organisms reported from monkeys. Among the species of monkeys found to be infected are the chimpanzee, gorilla and orang-utan, several other species of Old World monkeys and several species of New World monkeys. Of particular interest is the fact that parasites resembling the three species that occur in man have been found in the chimpanzee and gorilla (Reichenow, 1917, 1920). Attempts have been made to determine whether these are identical with the human species, with conflicting results. For example, Mesnil and Roubaud (1920) claim to have infected one of two chimpanzees by the intravenous inoculation of human blood containing *P. vivax*. These investigators failed to infect a chimpanzee by means of bites of *Anopheles* mosquitoes infected with *Plasmodium falciparum*. Failure to infect a young chimpanzee with human blood containing *P. falciparum* has been reported by Blacklock and Adler (1924). The same authors in 1922 also failed to infect two human beings with blood from an infected chimpanzee, and an *Anopheles* mosquito which they allowed to feed on the chimpanzee.

II. *Malarial Parasites of Birds*

That malarial parasites exist in birds has been known since 1890 (Grassi and Feletti). The name *Plasmodium præcox* is usually applied to the organism, but other specific names for parasites that have been found in various species of birds in different parts of the world have been suggested, and recently Hartman (1927) seems to have demonstrated that at least three species are present in English sparrows in the United States.

Plasmodium præcox is of considerable interest because this is

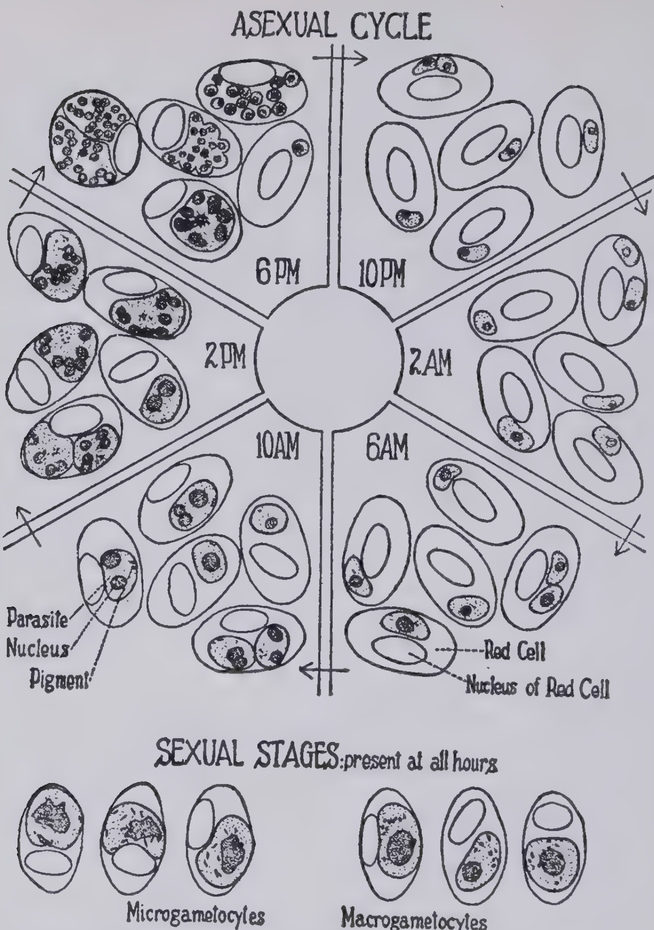


FIG. 54.—Diagrams representing the cycle of reproduction in bird malaria showing changes in size and variability. The outlines of the asexual stages (x 1500) of the parasites within the red cells, showing nuclei and pigment granules, were made at four-hour intervals during a consecutive period of twenty-four hours. Below are shown outlines of three microgametocytes and three macrogametocytes, which occur in small numbers at all hours throughout the infection. (After Taliaferro)

the species used by Ross in working out the sexual cycle of malarial parasites in mosquitoes. It is also of great value for purposes of teaching and investigation since it can be transmitted easily from sparrows to captive canaries by blood inoculation, and when the latter are once infected they appear to remain infected throughout their lives. The method of procedure is to prick a vein in the

leg and suck up a drop of blood into a syringe containing normal saline solution. This is then injected into the breast muscle or peritoneal cavity of a fresh bird. The average length of the prepatent period is about five days. The period of rise in the number of parasites is also about five days when from ten to 5,000 parasites per 10,000 red cells are present. Then a rapid fall in the number of parasites occurs and no more can be found in the blood except after long search. That the birds remain infected is evident from the fact that they suffer relapses, much as human beings do, and also by the fact that blood from the birds is infective to fresh birds.

It has been shown that the rate of reproduction of *P. præcox* in birds does not vary during the patent and subpatent periods and subsequent periods of relapse. It has also been demonstrated that the length of the asexual cycle (Figure 54) of a strain obtained from a sparrow in 1913, and that has been maintained in canaries ever since, is thirty hours (Taliaferro, L. G., 1925). During this period of over fourteen years this strain must have passed through approximately four thousand generations without the intervention of sexual reproduction and in a comparatively constant medium, the blood stream (Hegner, 1926). One canary infected with this strain remained infected for twenty-nine months (Whitmore, 1918), during which time about seven hundred asexual generations must have taken place.

Bird malaria is furthermore of value for the study of therapeutic agents. The drug known as plasmochin was first found to be effective against the plasmodia of birds and later of man (Roehl, 1926; Hegner and Manwell, 1927). Efforts to discover a better, more abundant and cheaper therapeutic agent than quinine are being made in various laboratories with the aid of birds infected with *P. præcox*.

III. *Malarial Parasites of Other Animals*

Malarial parasites have been described from a number of species of mammals and lizards and many new specific names have been proposed for them. Comparatively little, however, is known regarding their life-cycles in either the vertebrate or invertebrate host. Among the larger mammals in which malarial parasites have been noted are the goat and buffalo. Bats seem to be particularly susceptible to infection, several species having been named from these animals. Among other hosts in which plasmodia have been reported are the jumping rat and the squirrel.

Among the blood-inhabiting protozoa of lizards are a number of species that parasitize the red blood cells and resemble malarial parasites in their asexual cycle and in the production of gametocytes. The transmitting agent is unknown. Infected lizards have been reported from Africa and South America and a number of different specific names have been applied to the organisms discovered.

CHAPTER XIII

NEOSPORIDIA

The NEOSPORIDIA are not as well known as the TELOSPORIDIA, probably because many of them are extremely small and difficult to study, and comparatively few are to be found in man and domesticated animals. Of the three orders listed on page 120, the

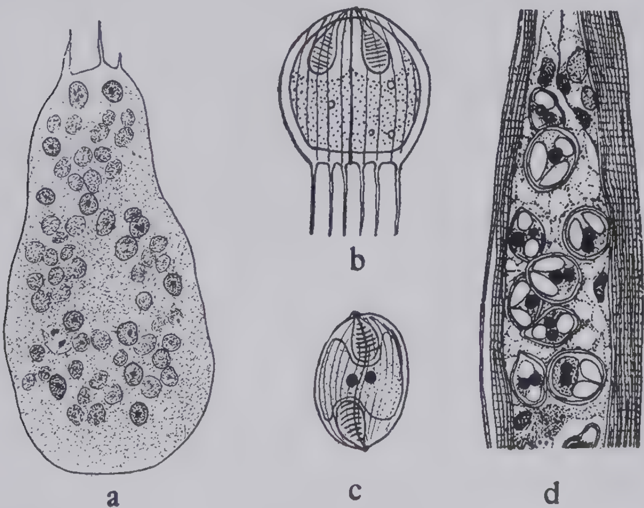


FIG. 55.—MYXOSPORIDIA.

a. *Chloromyxum leydigi.* Plasmodium from gall-bladder of dogfish, *Squalus acanthias*, showing spiky pseudopodia and nuclei (x 1600). (After Dunkerly)
b. *Mitraspora cyprini.* Fresh spore from kidney of carp, *Cyprinus carpio* (x 2000). (After Kudo)
c. *Myxidium oviforme.* Spore from gall-bladder of cod, *Gadus callarias* (x 1600). (From Kudo, after Parisi)
d. *Myxobolus orbiculatus.* Spores in muscle fibers of Gilbert's minnow, *Notropis gilberti* (x 900). (After Kudo)

MYXOSPORIDIA and MICROSPORIDIA are often placed together under the heading CNIDOSPORIDIA because their spores are provided with one or more polar capsules. The exact position of the SARCOSPORIDIA is still uncertain.

I. *Myxosporidia*

The conspicuous characteristics of this order are: (1) the trophozoite is a multinucleate plasmodium with pseudopodia as locomotor organs (Figure 55a) and (2) the spores are comparatively large and contain usually two polar capsules (Figure 55b, c; Figure 56a). Myxosporidia are parasites of cold blooded animals, principally fish. Kudo (1919) listed 237 species of which 223 parasitize fish, eight amphibia, four reptiles, one insects and one annelids. Tissues, especially muscle and integument, and body cavities, such as the gall bladder, urinary bladder and kidney tubules, are invaded by the organisms.

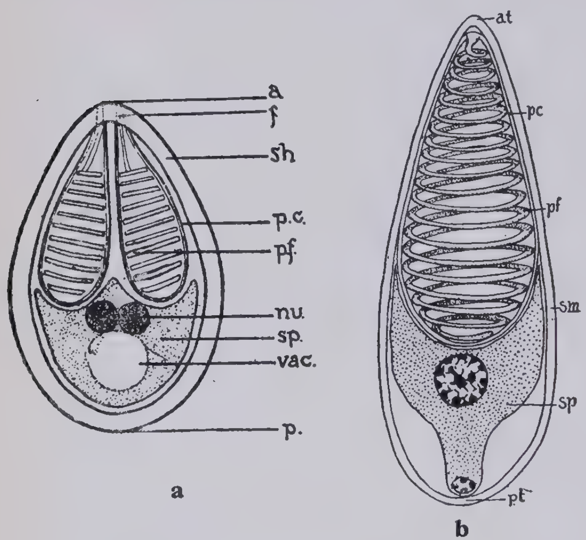


FIG. 56.—Diagrams showing the structure of neosporidian spores. (After Kudo)

a. Myxosporidian spore. *a.*, anterior end; *f.*, foramen of polar capsule; *nu.*, nuclei of sporoplasm; *p.*, posterior end; *p.c.*, polar capsule; *p.f.*, coiled polar filament; *sh.*, shell; *sp.*, sporoplasm; *vac.*, iodinophilous vacuole.

b. Microsporidian spore. *at.*, anterior end; *pc.*, polar capsule; *pf.*, polar filament; *sm.*, spore wall; *sp.*, sporoplasm.

The trophozoite is at first a uninucleate amœbula which grows as a result of absorption of nutriment from the host through the general body surface. Its nucleus divides again and again as growth proceeds until the large multinucleate plasmodial stage is attained. Division of the trophozoite (plasmotomy) may occur, but spore formation is the principal method of multiplication.

Spore formation occurs during the life of the individual, and the spores thus formed are liberated from time to time. The spore is of great importance as an aid in determining the fact that the

organism is a myxosporidium and the species to which it belongs, since the spores are very complicated in structure and differ widely from one another. The structure of a spore is shown in Figure 56a. There is a resistant sporocyst consisting of two valves within which, at the posterior end, is a cytoplasmic body consisting of sporoplasm with a vacuole, probably glycogenous in nature, and two nuclei, and, at the anterior end, two polar capsules within each of which is a coiled, and probably hollow, filament.

The infection of new hosts is brought about by the ingestion of spores, the polar filaments of which are extruded through an opening in the anterior end when stimulated by the digestive juices, and attach the rest of the spore to the intestinal epithelium. The sporocyst then opens and the sporoplasm creeps out in the form of an amœbula. The two nuclei in the sporoplasm fuse into one. The amœbula then penetrates the intestinal wall and is carried in the blood stream or lymph to the primary site of infection. Frequently infections are severe and bring about the death of the host.

II. *Microsporidia*

The MICROSPORIDIA are characterized by the presence of spores that are extremely small and possess usually only one polar capsule. Kudo (1924) records 178 species living in 222 different host species of which 149 are arthropods; the rest belong to other groups of invertebrates and to the cold-blooded vertebrates. Among the invertebrate hosts are included three species of sporozoa and one ciliate. Certain of the microsporidia are of great economic importance because they bring about the death of animals of value to man. For example, the species *Nosema bombycis* causes a chronic disease in silkworms known as pébrine. This species is generally distributed throughout the tissues of the host, including the eggs developing in the ovary. These eggs are deposited by the silkworm moth and the larvæ that hatch from them are thus infected by the so-called "hereditary" transmission. Pasteur was able to control silkworm disease, which once threatened to destroy the silk industry of France, by eliminating infected eggs which he was able to recognize with the aid of a microscope. Another important species economically is *Nosema apis* which causes nosema disease in honey-bees. Infection is brought about by the ingestion of spores and is limited to the digestive tract. Other species of MICROSPORIDIA are to a certain degree beneficial because they attack harmful insects, for example, the larvæ of several species of anopheline mosquitoes that

are carriers of human malaria may be infected (Hesse, 1904; Kudo, 1921, 1924). Infections with microsporidia have also been reported in the larvæ of black flies belonging to the genus *Simulium*. Many other species of insects, some of which are obnoxious, serve as hosts of microsporidia.

The life-cycle of a microsporidium is in general as follows. Spores are ingested by the host. As a result of the action of the digestive

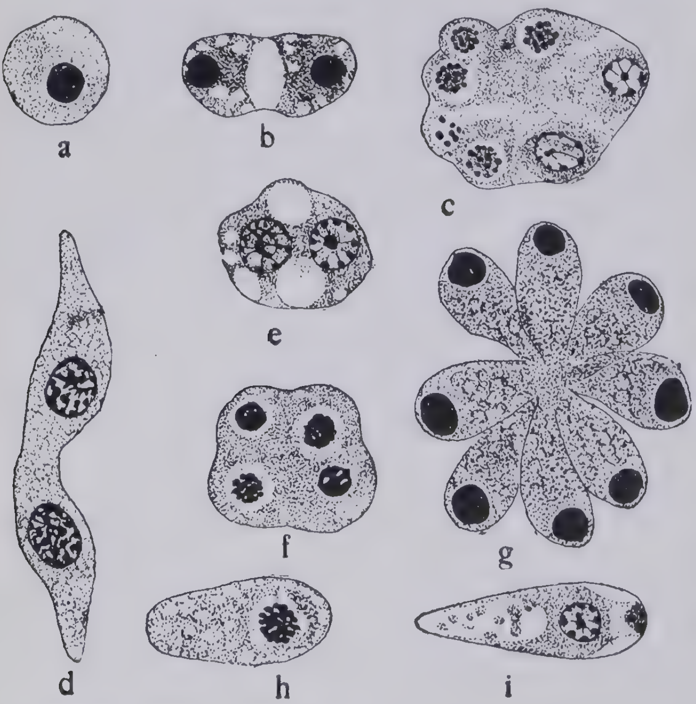


FIG. 57.—*Thelohania magna*, a microsporidium parasitic in the larva of the mosquito, *Culex pipiens*. Stages in the life-cycle (x 2360). (After Kudo)

a. Young schizont. b. Binary division. c. Multiple division. d. Binary division of the second type. e., f., g. Stages in formation of sporoblasts. h. Sporoblast. i. Young spore.

juices the polar filament is extruded and attaches the rest of the spore to the intestinal epithelium. After the filament becomes detached the cytoplasm (sporoplasm) within the spore creeps out through the opening left by the polar filament and becomes an amœbula. By means of pseudopodia the amœbula penetrates the epithelial wall and begins intracellular development. The tropho-

zoite, or schizont (Figure 57a), may multiply by binary fission (b), by budding or by multiple fission (c). Chain-like forms are sometimes produced by successive divisions without separation of the daughter cells. The merozoites produced by schizogony eventually become sporonts each of which transforms into a single spore, or the nucleus of the sporont may undergo successive divisions into two, four, eight or more, each of which becomes the center of a cell known as a sporoblast, the entire structure being known as a pansporoblast (Figure 57e, f, g). A single spore (i) develops from each sporoblast (h). When the host cells rupture, the spores pass into the lumen of the intestine and out of the body in the feces. There are many variations in the life-cycles of different species.

As in the MYXOSPORIDIA, the spore of the MICROSPORIDIA is of particular importance because of its value in classification. The structure of a typical spore is shown in Figure 56b. Spores are usually oval in shape and most of them are from 3 μ to 8 μ in length. There is a resistant sporocyst containing a single polar capsule and a mass of sporoplasm in which are two nuclei. The polar filament may be fifty times the length of the spore; its extrusion can be brought about by mechanical pressure or by acetic acid, hydrochloric acid and iodine water.

III. *Sarcosporidia*

The spores of the SARCOSPORIDIA do not contain polar capsules (Figure 58c). Sarcosporidia are parasites of vertebrates, being especially common in sheep, cattle and horses. They occur in reptiles and birds as well as mammals. The life-cycle of the sarcosporidium of rats and mice, *Sarcocystis muris,* is the best known. Spores ingested by mice hatch in the intestine, and liberate amœbulæ that penetrate the cells of the intestinal epithelium; here the trophozoites grow and multiply by schizogony. Apparently the merozoites migrate to the muscles where they become located in the fibers; here growth results in a multinucleate plasmodium which divides by plasmotomy. In the course of time the masses of parasites form long, slender, cylindrical bodies with pointed ends, known as "Miescher's tubes" (Figure 58a), within which immense numbers of sickle shaped spores measuring from 10 μ to 15 μ in length are formed.

Very little is known regarding the method of transmission of SARCOSPORIDIA. Mice become infected if they are fed on tissue containing spores (Smith, 1901). Mice have also been infected by

feeding them tissue of sheep containing *Sarcocystis tenella* (Erdmann, 1910). The mouse parasite, *S. muris,* is capable of infecting guinea-pigs (Negri, 1908; Darling, 1910). Half a dozen cases of sarcosporidiosis have been reported from man, the organisms usually being found at autopsy (Figure 58a, b).

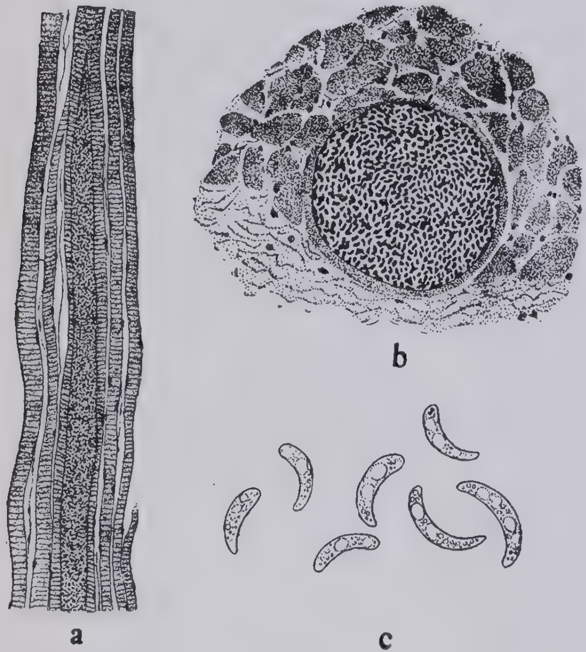


FIG. 58.—SARCOSPORIDIA.
a. Longitudinal section of Miescher's tube in muscle fibers of man (x 300). (After Baraban and St. Remy)
b. Transverse section of Miescher's tube in muscle fibers of man (x 300). (After Baraban and St. Remy)
c. *Sarcocystis muris.* Spores from the mouse. (After Koch)

Darling has suggested that the Sarcosporidia occurring in vertebrates are "side tracked varieties of parasites of invertebrate animals." In most cases no serious results are brought about by the infection, although *S. muris,* which spreads throughout the entire body, brings about death in mice, and death sometimes also occurs in sheep as a result of heavy infections. A toxic substance called sarcocystin, which is lethal to rabbits, was discovered by Pfeiffer (1891) in Sarcosporidia. The death of infected hosts may be due to this toxin.

CHAPTER XIV

PARASITIC INFUSORIA OF LOWER ANIMALS

I. *General Characteristics and Classification*

The INFUSORIA are characterized by the possession of cilia during a part or whole of their life-cycle. In most of them also the nuclear material is separated into a large macronucleus and a smaller micronucleus. Certain species belonging to the family OPALINIDÆ possess only one type of nucleus. The cilia of INFUSORIA cover the entire surface of the body in some species but are limited to certain areas in others. They are sometimes fused into spine-like processes, known as cirri, or side by side into membranelles. Most species ingest solid particles of food by means of a cytostome which leads into a cytopharynx, but a number of species, which are usually grouped together and called ASTOMATA, lack a mouth opening and absorb nutriment through the general surface of the body. The area surrounding the cytostome is known as the peristome; the arrangement of the cilia in this region differs in different groups and aids in classification. In some species there is an anal aperture, usually at the posterior end of the body, known as the cytopyge, and in certain of the OPALINIDÆ an excretory system with an external pore. One group of INFUSORIA, the SUCTORIA, possess cilia only in the young stages, the adults being provided with sucking tentacles.

Most of the INFUSORIA are free-living in fresh water or the sea. Many of them, however, are ectoparasites or entoparasites of man and other vertebrates and invertebrates. The INFUSORIA may conveniently be separated into two subclasses, the CILIATA and the ACINETARIA or SUCTORIA. The CILIATA may further be subdivided into four orders as follows.

Subclass I. CILIATA. Cilia in both young and adult stages.

Order I. HOLOTRICHA. Cilia usually covering the entire body and of approximately equal length. Examples: *Opalina, Isotricha.*

Order 2. HETEROTRICHA. Cilia of large size or fused into membranelles forming a spiral zone leading to the mouth. Examples: *Balantidium, Nyctotherus.*

Order 3. HYPOTRICHA. Body flattened dorso-ventrally; cirri on ventral surface. Examples: *Oxytricha, Kerona.*

Order 4. PERITRICHA. Cilia forming an adoral ciliated spiral and usually absent from the rest of the body; often sedentary in habit. Examples: *Vorticella, Trichodina.*

Subclass 2. ACINETARIA. Cilia in young stage but absent in adult stage; tentacles in adult stage; sedentary in habit. Examples: *Ophryodendron, Sphærophrya.*

II. *Nyctotherus cordiformis*

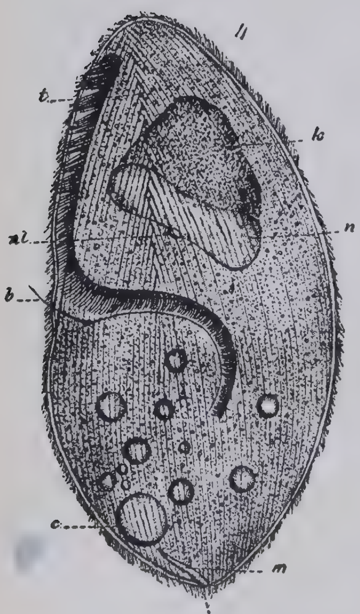


FIG. 59.—*Nyctotherus cordiformis* from the frog. *b*, opening into cytopharynx; *c*, vacuole; *n*, macronucleus; *nl*, micronucleus; *z*, anal aperture. (After Stein)

This species has been selected as a type of the ciliates by means of which the characteristics of this group may be illustrated. Species belonging to the genus *Nyctotherus* occur in various species of frogs and toads, in arthropods and other types of hosts. *N. cordiformis* (Figure 59) occurs commonly in the rectum of frogs and tadpoles. It ranges from 60 μ to 120 μ in length. The body is entirely covered by parallel rows of cilia. On one side, near the anterior end, is a peristome supplied with long adoral cilia. This leads to a cytostome near the center of the body which opens into a long curved cytopharynx. A row of plates of fused cilia extends from the peristome into the cytopharynx. The macronucleus, which lies near the center of the body, is kidney-shaped and the small macronucleus lies on its concave side. Near the posterior end is a single contractile vacuole and at the posterior end a cytopyge. Multiplication is by binary division. A cyst

stage occurs in the life-cycle of this species; it is oval and measures from 80 μ to 90 μ in length.

Another species of *Nyctotherus* that may easily be obtained for study is *N. ovalis* which occurs in the intestine of cockroaches and mole crickets. Other species have been reported from myriapods, termites and fish.

III. *Ectoparasitic Ciliates*

Among the ciliates are a number that live on the outside of aquatic animals. These represent all degrees of parasitism; some species attach themselves to another animal and are carried about with no further effort on their part; others move about on the surface of the host and may migrate from one host to another, and a few invade the tissues of the host and may be considered pathogenic.

I. AMPHILEPTUS

An example of an ectoparasitic holotrich is *Amphileptus branchiarum* (Figure 60). This species is parasitic on the gills of frog tadpoles (Wenrich, 1924). There may be from one to almost two hundred on the gills on each side of a tadpole. They are usually surrounded by the cuticular membrane of the gill epithelium. The ciliate, which

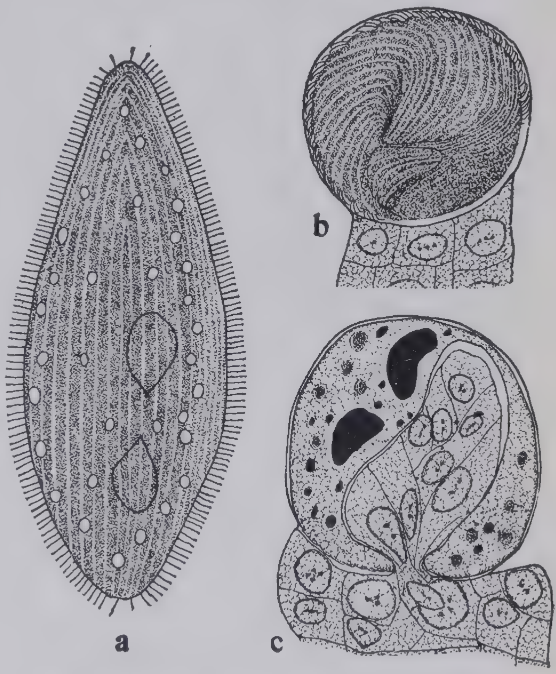


FIG. 60.—*Amphileptus branchiarum*, a holotrichous ectoparasite on the gills of tadpoles (x 550). (After Wenrich)

a. Free-swimming specimen showing cilia, surface striations, contractile vacuoles, and two nuclei.

b. Rounded-up specimen showing attaching membrane, cilia, and surface striations.

c. Specimen in optical section showing tissue of host being engulfed.

measures about 61 μ in diameter, is spherical in this stage and actively rotates within the capsule thus formed (Figure 60b). It severs and engulfs tissues surrounding it (Figure 60c). Binary fission and conjugation take place within the capsules. When outside of the capsules the ciliate is free-swimming, about 122 μ in length and flattened dorso-ventrally (Figure 60a).

2. KERONA

Kerona pediculus (Figure 61a) is a parasitic hypotrich which lives on the fresh-water cœlenterate *Hydra*. It prefers *H. fusca* and

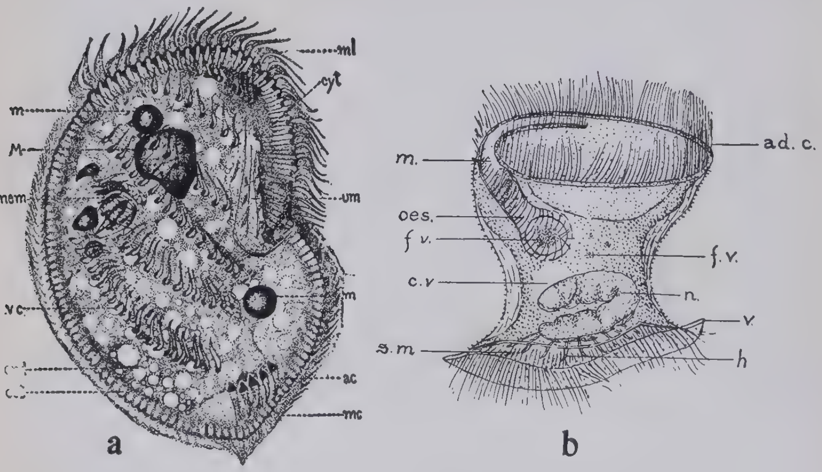


FIG. 61.—a. *Kerona pediculus,* a hypotrichous ectoparasite on *Hydra. ac.,* anal cirri; *cyt.,* cytostome; *ect.,* ectoplasm; *end.,* endoplasm; *m.,* micronucleus; *M.,* macronucleus; *mc.,* marginal cirri; *ml.,* membranelles; *nem.,* nematocyst; *vc.,* ventral cirri; *um.,* undulating membrane. (After Uhlenmeyer)
b. *Trichodina pediculus,* a peritrichous ectoparasite on *Hydra. ad.c.,* adoral cilia; *c.v.,* contractile vacuole; *f.v.,* food vacuole; *h.,* hooks; *m.,* mouth; *n.,* macronucleus; *oes.,* œsophagus; *s.m.,* striated membrane; *v.,* velum. (After Clark)

H. vulgaris to *H. viridis* (Uhlenmeyer, 1922). *K. pediculus* is modified for its mode of life; its anterior and lateral edges are flexible and fit closely to the host as the ciliate glides about on the surface. When detached from the host, it is free-swimming, but dies if it cannot find another suitable host, thus showing it to be an obligatory parasite. Living cells of the host are ingested by this parasite. Hydras thus attacked do not thrive and are eventually destroyed, but if they are freed from the parasites they again become vigorous.

3. TRICHODINA

Among the ectozoic peritrichs are several interesting species belonging to the genus *Trichodina*. *T. pediculus* (Figure 61b) lives on the outside of hydras, on the gills of certain salamanders and on the skin of tadpoles. The posterior end of the organism is modified as an organ of attachment by means of a flap-like velum and teeth-like structures. *T. pediculus* appears to be an obligatory parasite since it dies when removed from the gills of its host (Fulton, 1923) but is not pathogenic since it feeds on particles in the surrounding medium and not on the tissues of the host. Cross-infection from the gills of the salamander to *Hydra* has been successfully accomplished. Another species of the genus *Trichodina*, *T. urinicola*, has been described from the urinary bladder of salamanders, fish and toads (Fulton, 1923). This differs from *T. pediculus* in both morphology and habit. It is suggested that this species changed its habitat from outside of the body to the urinary bladder and that this has been accompanied by changes in structure. Trichodinas and keronas are sometimes associated on the same host. Clark (1866) says "At times the *Hydra* seems to be strangely knotted, and ungainly in outline, when upon close examination, we ascertain that it is crowded with a swarm of Keronas, upon several of whose convex backs, 1, 2, or 3 Trichodinas are seated, enjoying the pleasure of locomotion without the effort of producing it."

IV. *The Family Opalinidæ*

This is an interesting group of INFUSORIA that are very common in the rectum of frogs, toads and tadpoles. With the exception of one species, which occurs in a marine fish (*Box boops*), all of the approximately 150 species of opalinas live in the intestine of Amphibia. There are four genera (Figure 62), namely *Protoopalina* (a), with a cylindrical binucleate form, *Zelleriella* (b), with a flattened binucleate form, *Cepedea* (c), with a cylindrical multinucleate form, and *Opalina* (d), with a flattened multinucleate form. These are all characterized by a covering of cilia of equal length arranged in parallel rows, by the absence of a cytostome and by the presence of only one type of nucleus. The nuclei, however, are of considerable interest since in some species, during mitosis, two types of chromosomes have been observed, large chromosomes that lie near the surface of the mitotic spindle and smaller chromosomes in the form of slender rows of granules in the cen-

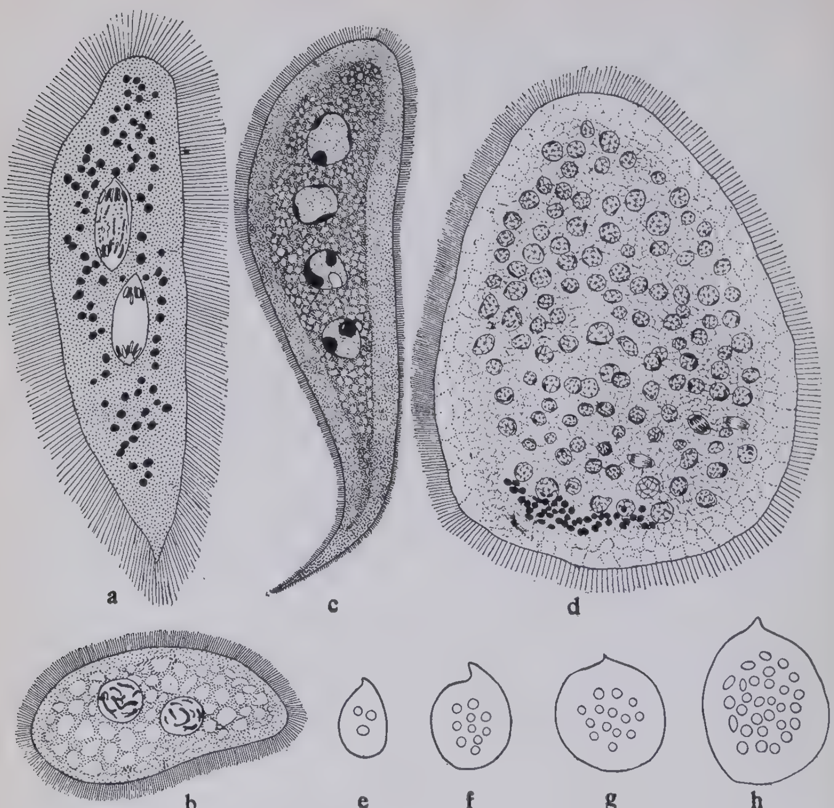


FIG. 62.—OPALINIDÆ. Examples of the four genera and a series of larval stages. (a-d from Metcalf, b and c after Bezzenberger; e-h, after Hegner and Wu)

a. *Protoopalina rhinodermatos.* A cylindrical form with two nuclei in the anaphase of mitosis (x 550).

b. *Zelleriella macronucleata.* A flattened form with two nuclei in the prophase of mitosis (x 500).

c. *Cepedea lanceolata.* A cylindrical form with four nuclei (x 900).

d. *Opalina ranarum.* A flattened form with many nuclei (x 250).

e. *Opalina larvarum.* Four stages in the growth of the young showing how the nuclei increase in numbers as the body increases in size (x 175).

ter of the mitotic figure. These two types of chromosomes may represent the material of the macronucleus and micronucleus, respectively, of other INFUSORIA. Another interesting characteristic of the OPALINIDÆ is the fact that in many species the nuclei come to rest in some stage of mitosis. The number of nuclei in the individuals of various species ranges from two to several thousand. A study of the growth of young opalinas of the species *O. larvarum*

(Figure 62e-h) indicates that there is a definite relation between the number and mass of the nuclei and the size of the body, the larger the body the greater the number of nuclei present (Hegner and Wu, 1921).

Opalina ranarum (Figure 62d) is the commonest and best known species belonging to this family. When alive it is opalescent in appearance. Some specimens reach a length of about a millimeter and may be seen with the naked eye. The body contains a large number of spherical nuclei evenly distributed throughout the cytoplasm. Many small spindle-shaped bodies of unknown character are present in the endoplasm. Reproduction is by binary division during most of the year, but in the spring rapid division results in the production of many small individuals which encyst and pass out in the feces of the frog. These cysts, which are 30 μ to 70 μ in diameter, when ingested by tadpoles, hatch in the rectum and give rise either to macrogametocytes or microgametocytes. The gametocytes, which contain from three to six nuclei, divide into uninucleate macrogametes or microgametes. These conjugate forming zygotes from each of which a young opalina develops. *Opalina ranarum* may be kept alive outside of the body of the frog for as long as three days in Locke's solution (Larson, Van Epps and Brooks, 1925) and apparently has been cultivated in Pütter's fluid (Tyler, 1926).

V. *Ciliates of Mosquito Larvæ*

Ciliates have been reported from a number of insects among which are the larvæ of mosquitoes. A few words about these are included here because mosquitoes are so important that any organisms that parasitize them are of particular interest. A species to which the name *Lambornella stegomyiæ* was given was discovered by Lamborn (1921) in the Malay States, parasitic in larvæ of the mosquito *Aedes* (*Stegomyia*) *scutellaris.* The ciliates were present in the gills, body cavity, head and antennæ and 157 specimens were counted in a moderately filled gill. The larvæ apparently were killed by the parasites which escaped when the gills ruptured shortly before death. Reproduction by fission was noted and cysts were observed attached to one of the larvæ (Keilin, 1921). Infection was probably by mouth.

Another species of ciliate was found by MacArthur (1922) in the body cavity of twenty-eight of eighty-seven larvæ and pupæ of *Theobaldia annulata* that were caught near Liverpool, England. All

of the infected specimens were killed by the parasites; some larvæ contained as many as a thousand ciliates. Wenyon (1926) considers this species to be *Glaucoma pyriformis.*

VI. *Entozoic Ciliates of Cattle*

A number of different species of mammals harbor ciliates in their intestinal tract. According to Buisson (1923) the types of

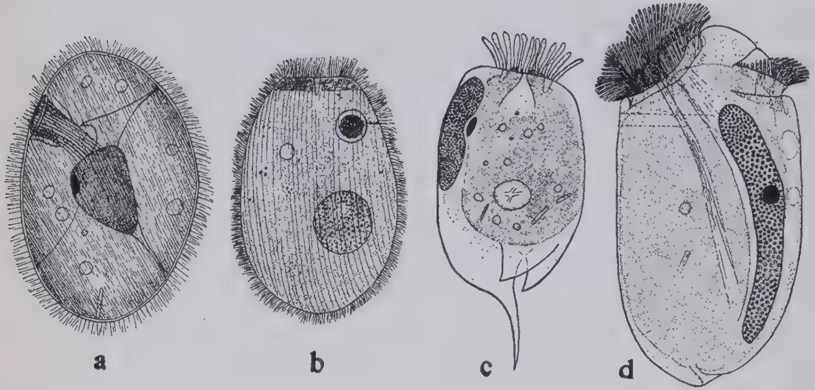


FIG. 63.—Ciliates of cattle. (From Becker and Talbott; b after Schuberg)
a. *Isotricha intestinalis* (x 500).
b. *Bütschlia parva* (x 850).
c. *Entodinium caudatum* (x 500).
d. *Diplodinium hegneri* (x 250).

mammals in which they occur, the number of species of hosts of each type and the number of species of ciliates are as follows:

	Species of Hosts	*Species of Ciliates*
Ungulates	11	128
Rodents	5	18
Primates	6	3
Hyracoidea	2	4
Proboscidea	1	1
	25	154

It is worthy of note that most of these ciliates occur in ungulates and rodents, which are herbivorous animals, and none occur in carnivorous animals. A number of other species have been described since Buisson made this compilation.

The first and second stomachs of cattle, that is the rumen and reticulum, are highly infected with protozoa, mostly ciliates. In this habitat two species of amœbæ, five species of flagellates and thirty-nine species and varieties of ciliates have been reported (Becker and Talbott, 1927). These belong principally to the genera *Isotricha* (Figure 63a), *Bütschlia* (b), *Entodinium* (c), and *Diplodinium* (d). The medium in the rumen and reticulum is neutral, or slightly acid or alkaline, and in the abomasum it is so strongly acid that, although cysts may pass through without injury, trophozoites are killed and digested. From two to sixteen or more species of ciliates may be present in the stomach of one animal. They feed on bacteria, other protozoa and fragments of the host's food. They are obligatory parasites since they die quickly

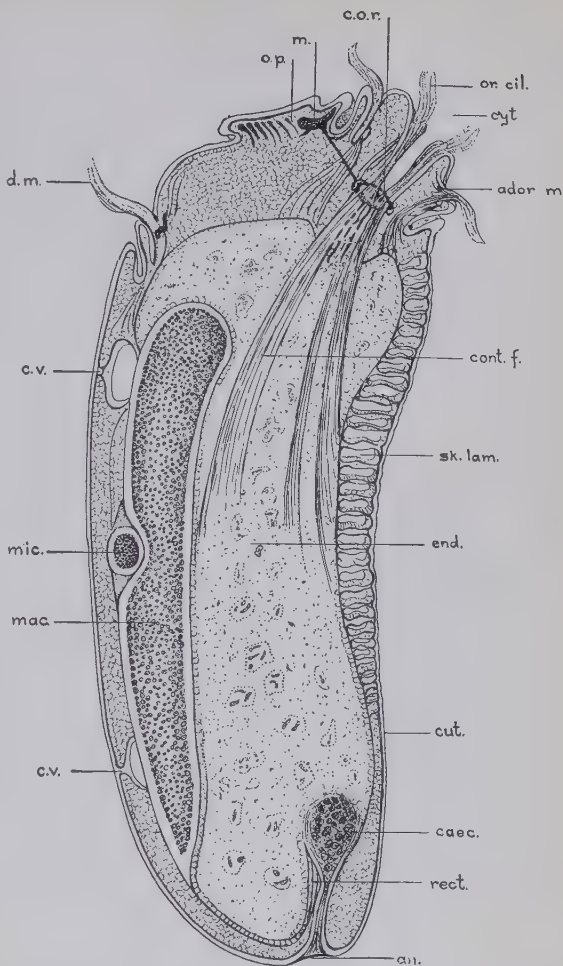


FIG. 64.—*Diplodinium ecaudatum.* A ciliate from cattle showing complicated structure. *an.*, anal opening; *ador. m.*, adoral membranelles; *cæc.*, cæcum; *cont. f.*, contractile fibers; *c.o.r.*, circumœsophageal ring; *cut.*, cuticle; *c.v.*, contractile vacuole; *cyt.*, cytostome; *d.m.*, dorsal membranelles; *end.*, endoplasm; *m.*, motorium; *mac.*, macronucleus; *mic.*, micronucleus; *o.p.*, operculum; *or. cil.*, oral cilia; *rect.*, rectum; *sk. lam.*, skeletal laminæ (x 700). (After Sharp)

if removed from their habitat. Their exact relations to the host are not known; some or all of them may be commensals or may assist in the digestion of the cellulose in the host's food and thus be symbiotic.

Among the ciliates of cattle are many species of great complexity. It is considered worth while to illustrate one of these here because protozoa are often erroneously considered to be simple organisms. The structure of *Diplodinium ecaudatum* is shown in Figure 64 and sufficiently described in the legend of this figure. Of particular interest is the so-called neuromotor apparatus consisting of a central motorium (M) which is connected with nerve rings and fibrils that make up a complicated system.

VII. *Ciliates of Monkeys*

Ciliates have been reported from various species of primates other than man. One species, *Balantidium coli,* which is supposed to be the same as *B. coli* in man, has been reported from the chimpanzee, orang-utan, baboon and several other species of both Old World and New World monkeys. A species named *Balantidium aragãoi* has been reported from *Cebus caraya* in Brazil (Cunha and Muñiz, 1927); this may, however, also be *B. coli.* Several species of the genus *Troglodytella,* a genus that does not occur in man, have been reported from the chimpanzee and gorilla (Figure 65). One species, named *T. abrassarti,* was reported from a sick chimpanzee in the Belgian Congo (Brumpt and Joyeux, 1912). A supposed variety, named *T. abrassarti* var. *accuminata,* has been reported from a chimpanzee in Kamerun, and another species,

FIG. 65.—*Troglodytella gorillæ.* A ciliate from the intestine of the gorilla (x 250). (After Reichenow)

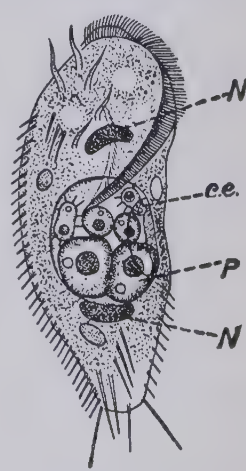


FIG. 66. — *Sphærophrya.* A suctorian endoparasitic in a hypotrichous ciliate, *Stylonychia. N,* macronuclei of *Stylonychia.* P, parasitic suctorian. *c.e.,* ciliated embryo. (From Minchin. After Stein)

named *T. gorillæ,* from a gorilla in the same locality (Reichenow, 1926).

Balantidium coli appears to be pathogenic in monkeys. Cross-infection experiments indicate that the balantidia of man, monkey and pig belong to a single species. For example, Walker (1913) succeeded in infecting twelve of thirteen monkeys by feeding them cysts from pigs; one of four monkeys by injecting trophozoites from pigs per rectum; two of three monkeys by injecting trophozoites from man per rectum; one monkey by injecting both cysts and trophozoites from man per rectum; but failed to infect one monkey which was fed cysts from man. Brumpt (1909) succeeded in infecting a pig per rectum with balantidia from monkeys.

VIII. *Parasitic Suctoria*

Various types of parasitism are exhibited by the SUCTORIA; among these are ectoparasites that attach themselves to more or less definite species of aquatic animals, and endoparasites which live within other hosts. *Ophryodendron* is an ectoparasite that lives on hydroids and *Sphærophrya* is an endoparasite that lives within the bodies of free-living ciliates such as *Paramœcium* and *Stylonychia* (Figure 66).

CHAPTER XV

PARASITIC CILIATES OF MAN

I. Balantidium coli

1. BALANTIDIUM COLI IN MAN, PIG AND MONKEY

The only species belonging to the class INFUSORIA that is known with certainty to be parasitic in man is the ciliate *Balantidium coli* (Figure 67). Ciliates indistinguishable from *B. coli* and supposed to belong to the same species are common inhabitants of pigs, have been reported from various species of monkeys and may be parasitic in the cecum of guinea-pigs (Scott, 1927). A second species of *Balantidium, B. suis,* was described from pigs by McDonald (1922). This species has a more pointed posterior end and the greatest diameter is at or anterior to the center; whereas *B. coli* is rounded at the posterior end and the greatest diameter is posterior to the center. *B. suis* is approximately the same length as *B. coli* but not as broad, the average length of both species being 86 μ, but the breadth of *B. coli* 66 μ and that of *B. suis* 43 μ. The cytostome of *B. suis* is not almost terminal as in *B. coli* but is located about one fifth of the length of the body posterior to the anterior end. The macronucleus of *B. suis* is rod or sausage-shaped, at least one half of the length of the entire animal and about one fourth as broad as long; whereas the macronucleus of *B. coli* is bean-shaped, about one third of the length of the entire animal and about one half as broad as long. Certain balantidia reported from a Brazilian monkey, *Cebus variegatus,* by Hegner and Holmes (1923) differ from both *B. coli* and *B. suis.* They are much smaller than either of these forms, averaging 44 μ in length and 25 μ in breadth. They are more slender than *B. coli* but not as narrow as *B. suis.* A careful study of the genus *Balantidium* is necessary before the exact status of the various species can be considered established.

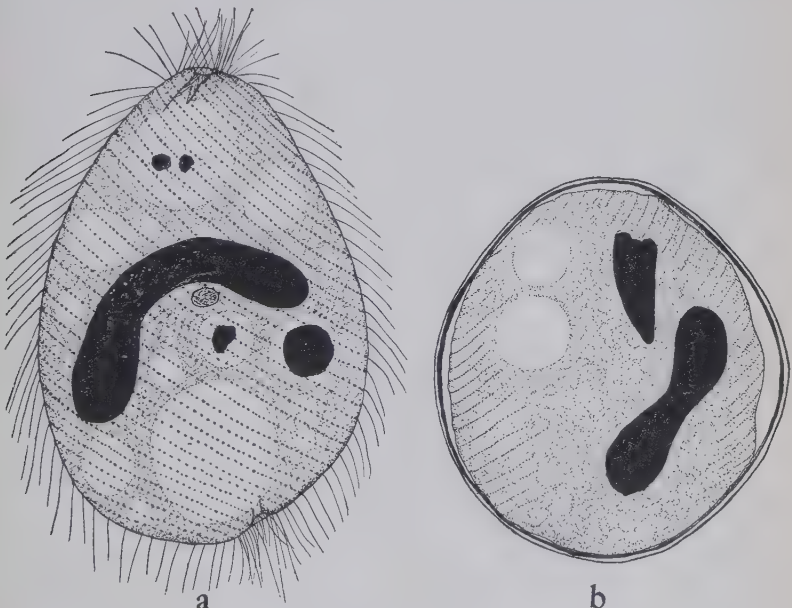
2. LIFE-CYCLE

The life-cycle of *Balantidium* coli is not known in detail. The trophozoite lives in the large intestine where it reproduces by trans-

verse binary fission. Single organisms may encyst and pass out of the body in the feces; these represent the infective stage which brings about the transmission of the species to new hosts. The conjugation of two organisms followed by secretion of a cyst wall has been reported but details are lacking.

3. MORPHOLOGY

Trophozoite (Figure 67a). *Balantidium coli* is oval in shape, somewhat narrow and pointed at the anterior end and broader and rounded at the posterior end. The peristome, which is located



a b

FIG. 67.—*Balantidium coli.* a. Trophozoite. b. Cyst (x 1000). (a. After Hegner; b. after Dobell and O'Connor)

near the anterior end, makes it possible to distinguish the ventral from the dorsal surface. *B. coli* is very large compared with other human protozoa and varies greatly in size; it ranges from 30 μ to 200 μ or more in length and from 20 μ to 70 μ in breadth, the usual range in size being from 50 μ to 70 μ long by 40 μ to 60 μ wide. The average length is 86 μ and the average breadth 66 μ

and the ratio of length over breadth is 1.3. The entire body of the trophozoite is covered with cilia, which are arranged in parallel longitudinal rows in a somewhat spiral course; they are 4 μ to 6 μ in length on the general body surface and 8 μ to 12 μ in length on the adoral zone which surrounds the peristome. The cilia lie in the grooves between the ectoplasmic ridges and each cilium arises from a basal granule. The peristome is a slit-like depression on the ventral surface at the anterior end, at the bottom of which is the cytostome leading into the cytopharynx. A nonciliated oral plug in the peristome may completely close the cytostome (McDonald, 1922). At the posterior end is a rectal vacuole into which excretory materials are collected and from which they are forced out through a cytopyge. The body of *B. coli* is covered by a pellicle that is thrown up into parallel longitudinal ridges. Just beneath the pellicle is a layer of clear ectoplasm and within this is the more fluid granular endoplasm.

Within the body of *B. coli* are a macronucleus, a micronucleus, two contractile vacuoles and a number of food vacuoles. The macronucleus is large and kidney-shaped. It lies usually near the center of the body in a more or less oblique position. Chromosome-like masses of chromatin, constant in number (five to ten), have been observed in the macronuclei of balantidia from several species of hosts in addition to what appear to be minute chromatin granules scattered throughout the nuclear substance (Hegner and Holmes, 1923); the significance of these chromosome-like masses is not known. The micronucleus is small, subspherical in shape and lies against the macronucleus or in a depression in it. The two contractile vacuoles are located near the periphery of the body, one close to the posterior end and the other just anterior to the middle of the body; they expel excretory material in solution to the outside when they contract. The number of food vacuoles in the body depends on the state of nutrition of the organism. Food particles, such as starch grains, bacteria, red and white blood cells and organic débris, are driven by the adoral cilia through the cytostome and into the cytopharynx at the end of which the food vacuoles are formed. These food vacuoles are carried about in the endoplasm by a cytoplasmic movement known as cyclosis. Within them digestion is accomplished by enzymes secreted by the surrounding cytoplasm. The digested material passes out and is assimilated and the undigested particles are extruded through the cytopyge. A neuromotor apparatus has been described by McDonald (1922) in *B. coli*. It consists of a motorium, which is supposed to serve as a coördinat-

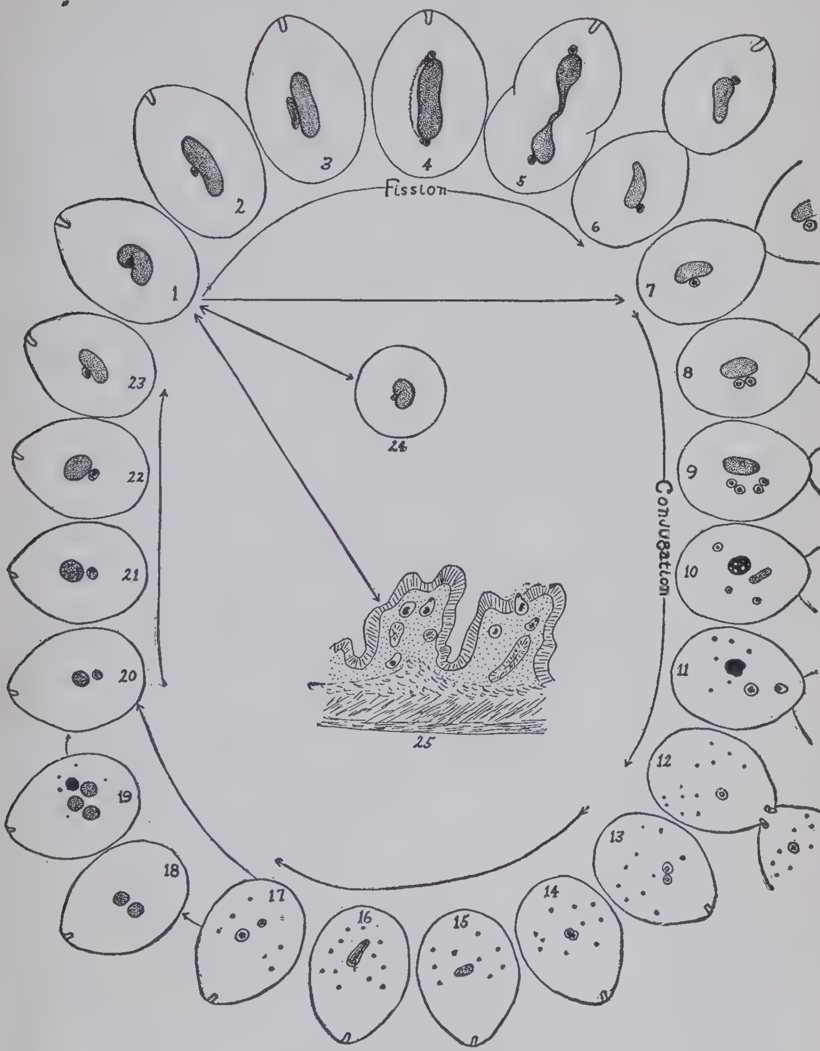


FIG. 68.—*Balantidium coli.* Diagrams illustrating stages in the life-cycle. 1. Normal trophozoite. 2-6. Stages in binary fission. 7-12. Stages in conjugation (one conjugant and a portion of the other are shown) illustrating the divisions of the micronuclei and breaking down of the macronucleus. 13-23. Reconstruction stages after separation of conjugants. 24. Cyst; the arrows indicate that the cyst may develop from or give rise to a normal trophozoite. 25. Intestinal wall of guinea-pig invaded by balantidia. (After Scott)

ing center, and a large number of fibrils which play a part in the swimming and feeding movements of the organism.

The trophozoite of *B. coli* reproduces by transverse binary fission (Figure 68, 1-6). The macronucleus apparently divides by amitosis; it becomes dumb-bell shaped and then the two approximately equal parts separate, one passing to either end of the body. The micronucleus undergoes a sort of intranuclear mitosis; one daughter micronucleus passes to each end of the body. Then a constriction appears at the center of the organism and the body is divided into two approximately equal parts; the cytostome of the parent is continued in the anterior daughter and a new cytostome arises at the anterior end of the posterior daughter cell. Rapid binary division sometimes results in "nests" of very small specimens within the tissues of infected hosts; these have been described as groups of spores (Walker, 1909) but sporulation probably does not take place in this species.

The process of conjugation apparently occurs in the life-cycle of *B. coli* (Figure 68, 7-23), but is not known in detail. Two specimens adhere to each other by their peristomes. They then secrete a cyst wall within which they are supposed to become completely fused. The further history of these conjugation cysts has not been worked out. The formation of buds at the posterior end of *B. coli* has also been reported (Ohi, 1924) but the description is not convincing and requires confirmation.

Cyst. Besides the conjugation cysts just described, cysts containing a single organism occur in the life-cycle of *B. coli* (Figure 67b). The stimulus that initiates the process of encystment is not known. The ciliate secretes about itself a wall consisting of a thick outer layer and a thinner inner layer. These cysts, which are spherical or ovoid, measure from 50 μ to 60 μ in diameter. At first the organism moves about actively inside the cyst wall but eventually becomes quiescent and degeneration of the cilia then occurs. Encystment appears to be more frequent in the pig than in man.

4. HOST-PARASITE RELATIONS

Transmission. As is the case with other intestinal protozoa, *B. coli* is transferred from one host to another in the cyst stage, and it is the host that brings about its own infection, since the cyst is incapable of movement. The ingestion of food or drink contaminated by fecal material containing cysts is the probable method of infection. Trophozoites may possibly also be infective since they

may live at room temperature for as long as ten days (Rees, 1927) and, at least in small animals (guinea-pigs), they are capable of passing unharmed through the stomach and small intestine and of reaching the cecum, which is the primary site of infection (Hegner, 1926). Cysts are more resistant than trophozoites; they will live at room temperature for two months if kept in a moist condition and for from one to two weeks when dried in the shade (Ohi, 1924). It is generally supposed that human beings become infected by ingesting balantidia from pigs, since cysts appear to be rare

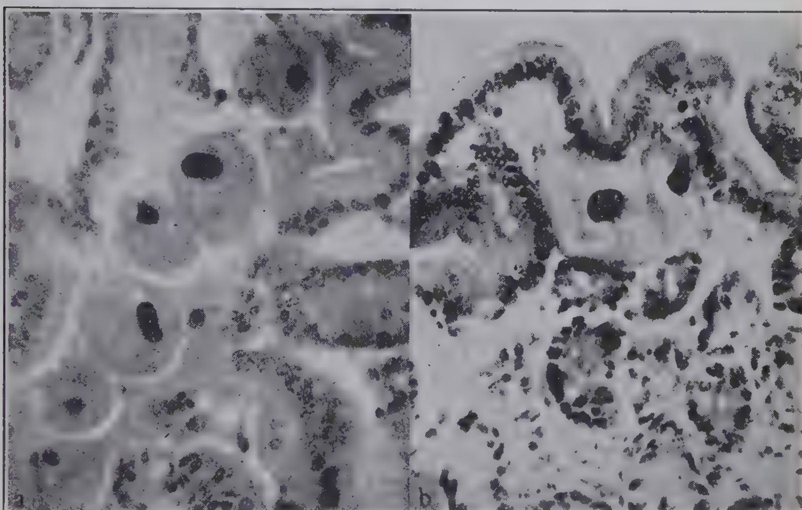


Fig. 69.—*Balantidium coli.* Photographs of sections of the intestinal wall of an infected guinea-pig showing balantidia in the lumen of the glands (a) and within the mucosa (b). (After Scott)

in man and since a large percentage of human cases can be traced, more or less definitely, to pigs. Direct infection of man with cysts of *B. coli* from the pig has been attempted but with negative results (Grassi, 1888). Positive infections of monkeys have been obtained by injecting balantidia from pigs per rectum (Brumpt, 1909), by injecting trophozoites from man per rectum and by feeding monkeys cysts from pigs (Walker, 1913).

Pathogenesis. Where excystation occurs and the factors involved are not known. The primary site of infection is the large intestine, although cases have been reported of balantidia in the ileum (Reis, 1923). Apparently the excysted organisms are able to live and re-

produce within the intestinal lumen without access to the tissues of the host; such organisms are non-pathogenic and the host is a carrier. In some cases, however, the organisms attack the intestinal wall and thus become pathogenic (Figure 69). Walker (1913) believes that the ciliates bore their way mechanically into the tissues of the intestinal wall thus causing irritation resulting in hyperæmia of the mucosa. The host tissues appear to be dissolved by ferments secreted by the parasites and used as food. Ulcers are formed and clinical symptoms appear, varying in severity from diarrhea to dysentery. The disease produced is known as balantidiasis, balantidial dysentery or ciliate dysentery.

5. CULTIVATION

Living balantidia may be obtained for study at any abattoir where pigs are slaughtered. McDonald (1922) found 68 per cent of 200 pigs infected, the parasites being most numerous in the cecum and first three or four feet of the colon. Barret and Yarbrough (1921) were the first to cultivate *Balantidium coli* in artificial medium; this consisted of sixteen parts of 0.5 per cent salt solution plus one part of inactivated human blood serum. Feces containing balantidia were inoculated at the bottom of tubes and incubated at 37° C. Maximum growth occurred in from forty-eight to seventy-two hours and subcultures were made every second day. Rees (1927) has confirmed this work although he used a modified Ringer's solution instead of 0.5 NaCl and substituted with success Loeffler's dehydrated blood serum for the human blood serum. A pure culture was obtained by picking out single individuals with a micropipette and inoculating them into test-tubes containing the medium. Cultures of the balantidia from the guinea-pig were also obtained by Rees and cysts occasionally appeared in these cultures.

II. *Doubtful Ciliates of Man*

A number of ciliates have been reported from man by various investigators but none of them has as yet been established as a regular inhabitant of the human digestive tract. Among these are species belonging to the genera *Balantidium, Nyctotherus, Chilodon, Uronema* and *Colpoda.* It seems probable that all of these are poorly fixed specimens of *B. coli,* or coprozoic ciliates that have

accidentally found their way into fecal material after it was passed or had passed through the digestive tract in the cyst stage and excysted in the stool. *B. minutum* (Figure 70) was reported by Schaudinn (1899) and has been recorded by several investigators since then. Several varieties of this so-called species and of *B. coli* have been described from Italy, Germany, Honduras and Albania. A species named *Nyctotherus faba* was also described by Schaudinn (1899) from the same patient in whom *B. minutum* occurred. Several other species belonging to this genus have been reported from man. The free-living ciliate, *Chilodon uncinatus*, has been reported from human feces on several occasions. The species described from human feces as *Uronema caudatum* by Martini (1910) and *Colpoda cucullus* by Schultz (1899) are no doubt also free-living ciliates living under coprozoic conditions.

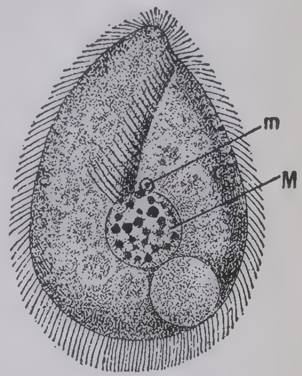


FIG. 70.—*Balantidium minutum* described from man. M, macronucleus. m, micronucleus (x 1500). (From Brumpt. After Schaudinn)

Section II

HELMINTHOLOGY

BY

DONALD L. AUGUSTINE

CHAPTER XVI

INTRODUCTION TO THE HELMINTHS

I. *General Classification*

The parasitic worms belong to a group of animals known as the helminths. This group was regarded by early zoölogists, Cuvier and others, as a single united division, not only biologically apart from other animals but systematically apart as well. On account of the great variety in the different types included in this division, the group is no longer regarded a systematic one. The association of its members is now looked upon as being only biological and the term "helminth" is used to specify certain lowly worms which lead parasitic lives.

Systematically, the helminths are represented in two different phyla, (1) PLATYHELMINTHES, or flatworms, and (2) NEMATHELMINTHES or threadworms. Within these phyla the helminths are placed under five groups which usually rank as classes, namely, TREMATODA or flukes, and CESTODA or tapeworms under the phylum PLATYHELMINTHES, and NEMATODA or threadworms, GORDIACEA or hair worms and ACANTHOCEPHALA or proboscis-worms under the phylum NEMATHELMINTHES. While the GORDIACEA and ACANTHOCEPHALA have been classed by most writers as allies of NEMATODA they have little else in common with the nematodes except a general form of body and the parasitic habit. Some authorities regard the GORDIACEA as degenerate annelids, and others have pointed out possible relationships between the ACANTHOCEPHALA and CESTODA. The GORDIACEA and ACANTHOCEPHALA are therefore of uncertain systemic position and until the morphology and embryology of these groups are better known, their affinities must remain problematical.

Phylum PLATYHELMINTHES. METAZOA; triploblastic; bilaterally symmetrical; with bodies leaf-shaped or band shaped; mostly hermaphroditic; without body cavity; alimentary canal incomplete or entirely lacking.

Class I. TURBELLARIA. PLATYHELMINTHES with bodies cylin-

drical to spindle-shaped; with ciliated ectoderm; with digestive system; development direct; with free-living habit.

Class 2. TREMATODA. PLATYHELMINTHES; unsegmented bodies oval or leaf-shaped; ciliated ectoderm present only in larval stage; with digestive system; living as ectoparasites or endoparasites; mostly hermaphroditic; with development by metamorphosis or alteration of generation; almost all, in the adult stage, parasites of vertebrates.

Class 3. CESTODA. PLATYHELMINTHES; ribbon-shaped or band-shaped; segmented; without mouth or alimentary canal; hermaphroditic; adults exclusively parasitic in alimentary canal of vertebrates.

Phylum NEMATHELMINTHES. METAZOA; triploblastic; bilaterally symmetrical; with elongated, cylindrical, unsegmented bodies; without cilia or appendages arranged on a regularly segmental plan, sexes usually separate; with body cavity in which organs float.

Class I. NEMATODA. NEMATHELMINTHES with bodies usually spindle-shaped, tapering at both ends rather than cylindrical; body cavity not lined by epithelium; alimentary canal usually complete; free-living and parasitic forms.

I. APPENDIX TO NEMATHELMINTHES

GORDIACEA. NEMATHELMINTHES with bodies generally uniformly cylindrical with blunt, rounded ends; body cavity lined by epithelium; alimentary canal atrophied in sexually mature worms; parasitic in larval stage; adults free in bodies of fresh water.

ACANTHOCEPHALA. NEMATHELMINTHES with bodies tapering posteriorly; no trace of alimentary canal at any stage of development; with a proboscis; both larval and adult stages parasitic.

II. *Distribution and Incidence*

The helminths are world-wide in their distribution, and their incidence among the lower vertebrates is higher than in man. The presence of parasitic worms among the lower vertebrates is quite general. In man, however, their occurrence is apt to be greater in the tropical and subtropical countries where the climate and habits of the people are more favorable for their dissemination. Infection with a single species in such an environment may occur in 98 per cent of a given population and often several species may occur in a single host. It is a common occurrence to find hookworms, ascarids

and whipworms in the same person. Often the number of different species of helminths in a single host is surprisingly high. In many instances, only a few parasites of a given species may be present in an infected host, or again, the number may be very large. Infections with 1000 hookworms, *Necator americanus,* are not uncommon. Pinworms also occur often in very great numbers. Perhaps the largest number of worms recorded from a single person is that reported by Sambuc and Baujean (1913). These authors obtained 21,000 liver flukes, *Clonorchis sinensis,* at autopsy from a patient in Indo-China. Some of the helminths are parasites of a single host species while others are common parasites of a more or less wide range of animals. For example, the pinworm, *Enterobius vermicularis,* and the hookworm, *Necator americanus,* are parasites only of man, while the lung fluke, *Paragonimus westermani,* not only is a parasite of man, but also occurs in tigers, cats, dogs and swine.

The adult stages of helminths are more or less restricted to a single organ or system of organs of their hosts, occurring mainly in the intestines or certain portions of the alimentary tract, or the liver, the lungs or in the connective tissue. Hence, the derivation of their common names, such as the eye worm, the seat worm, the lung fluke, the liver fluke, the blood fluke and the like. Certain larval stages are not restricted, however, to a single organ and may have considerable range in their habitats for development. *Cysticercus cellulosæ,* the larval stage of the pork tapeworm of man, infects the intermuscular connective tissue, the brain and eye and has been found in many other localities. The hydatids of *Echinococcus* develop in the liver, lungs, kidneys, spleen, omentum, heart, brain and various muscles. The larvæ of the trichina worms, *Trichinella spiralis* on the other hand, are most selective, accepting only the striated muscles of their host for encystment.

I. FACTORS DETERMINING DISTRIBUTION AND INCIDENCE

The type of life-cycle of a given species of the parasitic worms determines to a great extent its geographical distribution and incidence. In the majority of cases the parasitic stage alternates with a longer or shorter non-parasitic period. The development may be direct from host to host, or it may be exceedingly complicated involving both an alternation of generations and an alternation of hosts. The commonest and most widely distributed species of the helminths are those which have no intermediate host, with little or no development in the free stages, and infect a new host with

ova which have escaped in the feces of the previous host. Thus the nematodes, *Ascaris lumbricoides, Trichuris trichiura* and *Enterobius vermicularis,* and the tapeworm, *Hymenolepis nana,* have become cosmopolitan in their distribution. The helminths which have a longer non-parasitic stage with larvæ developing in the soil are limited in their distribution to the warmer countries where the temperature and other factors are most favorable for their development and existence. The parasitic worms having intermediate hosts are necessarily limited in their distribution to the distribution of these hosts. The FILARIIDÆ are transmitted only by the bites of certain blood-sucking insects, and are therefore limited to the distribution of their specific intermediate hosts. It is probably for this reason that the eye worm of man, *Loa loa,* has not become established beyond the western coast of Africa, the habitat of its essential hosts, the mango flies, *Chrysops dimidiatus* and *Chrysops silacea.* On the other hand, there are several helminths, including the tapeworms, *Tænia saginata* and *Tænia solium* of man, whose intermediate hosts are cosmopolitan. In such cases we may expect to find the parasite to be also cosmopolitan, providing certain habits of the host are favorable for their transmission. Many of the parasitic worms require certain food habits for their entrance into their final hosts. *Tænia saginata* and *Tænia solium* are introduced into their final hosts through the eating of infected, raw or insufficiently cooked beef or pork respectively, and the fish tapeworm, *Diphyllobothrium latum,* and the liver fluke, *Clonorchis sinensis,* by the eating of raw or insufficiently cooked fish. *Trichinella spiralis* depends for its spread upon the eating of raw or underdone pork containing the infective cysts of this parasite. Thus, the distribution of these helminths is limited to those countries, or certain districts within a given country or city, where raw meats or insufficiently cooked meats are eaten.

III. *Effects Produced by Helminths on the Host*

The relation of some of the helminths to disease is not always definite, while in other cases the pathogenicity is well established. In many helminth infections where clinical symptoms are manifest, the worms occur in relatively large numbers and the infection is of fairly long standing. On the whole, the onset of clinical manifestations due to the presence of parasitic worms is usually of a gradually increasing scale of severity rather than a rapid onset as

in the case of infectious bacterial diseases. This is due to the fact that there is no multiplication of worms within the host and the disease caused by them is the result of frequent exposures to the infective stages. There are, however, some exceptions, particularly in the case of infections with the trichina worms, *Trichinella spiralis,* whose progeny remain within the host harboring the adult. In this case the clinical symptoms may appear within a relatively few hours after the ingestion of the infective cysts of the worm, and the different stages in the course of the disease may be correlated with the different stages in the development of the parasite.

There is also great variation in the susceptibility of different individuals to the attack of helminths. The worms may produce marked clinical symptoms in certain individuals while in others, equally parasitized, the infection may be entirely unnoticed. The common tapeworms of man may be unaccompanied by any symptoms in the healthy adult while in debilitated individuals or in children they may give rise to serious disorders. This is quite generally true with most helminth infections, namely, that marked clinical symptoms are most frequently met with in undernourished or otherwise weakened individuals.

The injuries produced by the helminths depend on several factors, such as the size of the parasite, its mode of life, its habits within the host, the number present and the organs or tissues occupied. In general, the presence of helminths may injure the host in one or more of the following ways:

1. ROBBING OR STARVING THE HOST

All of the helminths derive their food from the host. The amount of injury to the host through the loss of such nourishment depends largely on the size of the parasite and on the number present. In most cases, the loss may pass unnoticed while in other instances, especially in the growing young, it may be a serious hindrance to the normal development.

2. WOUNDING THE HOST

Parasitic worms may wound the host either through their feeding habits or by boring through the tissues of the host during their migrations. Hookworms feed upon the intestinal mucosa of their hosts, tearing it loose with their powerful teeth. When they

occur in large numbers, the loss of blood from such wounds may be considerable. Further danger may arise from bacterial invasion through these wounds resulting in ulceration. *Ascaris lumbricoides* is frequently known to migrate out of its normal habitat, the small intestine, and in so doing may penetrate through the intestinal wall and cause a fatal peritonitis due to bacteria which are carried with it. Adult ascarids have been found to have penetrated practically every organ of the body. In such instances the danger to the host is not limited to the wandering action of the worm alone but to the invasion of bacteria as well.

The wounding action of the helminths is not limited to the presence of adult worms, but is also met with in some larval stages. The infective larvæ of the hookworms and *Strongyloides stercoralis* among the nematodes, and the cercariæ of the blood flukes gain entrance to their hosts by actively penetrating the host's skin. In so entering their hosts, they produce an inflammation or dermatitis at their port of entry. Here again, complications often arise due to secondary bacterial infections and pustulation or extensive ulceration may follow. A number of larval nematodes have extensive courses of migration within the body of the host before the adult stage is reached. The larvæ of the hookworms and *Ascaris,* after their entrance into the portal system, pass through the liver and eventually to the lungs, where they break through the capillaries to the air spaces on their way up the trachea to the esophagus and from thence into the intestines. Should the number of worms be large the hemorrhage may be considerable and the resultant inflammation be so great that generalized pneumonia is likely to occur. The danger from the wounding action of the helminths then does not lie entirely in the wound itself; for, through the wound, they may bring about, or prepare the ground for a serious, superimposed infection by other organisms.

3. MECHANICAL IRRITATION

Hyperplasia and overgrowth of specialized tissue are often the result of irritation from the presence of certain helminths. *Œsophagostomum* is known to produce tumor-like formations in the intestinal mucosa; and hyperplasia of the lymphatic glands and tissues may result in infections with *Wuchereria bancrofti.* Fibiger (1913) has demonstrated the production of gastric carcinomata with metastases in various organs in rats by a nematode, *Gongylonema neoplasticum.*

4. MECHANICAL OBSTRUCTION

Mechanical obstructions are often caused by the helminths when they occur in large numbers. The liver flukes may completely block the bile-ducts causing retention of bile and jaundice. Stasis of the lymph, giving rise to lymphangitis, varicose glands, lymph scrotum and elephantiasis has been attributed to adult filaria plugging the thoracic duct. The common parasite of man, *Ascaris lumbricoides*, is frequently found in such large numbers that the intestine is entirely blocked by them.

5. TOXIC EFFECTS

Injuries due to the excretion and absorption of toxins liberated by helminths are often more in evidence than mere mechanical wounding action. The marked clinical symptoms so often accompanying worm infection are usually of toxic origin. Recent investigation by De Langen (1927) and others have shown that the appearance of disease symptoms in ancylostomiasis is due to a toxic factor which exercises a disturbing influence on various organs; and, by means of its harmful influence, especially on the bone marrow, is responsible for the marked anemia in that disease. These toxins are also believed to be the cause of abnormal excretion of the kidneys in sufferers who show typical symptoms from ancylostomiasis.

Toxic symptoms such as fever, urticaria, dermatographia, and edema have been noted in trematode infections, and an anemia simulating pernicious anemia may occur in cases of infections with the fish tapeworm of man, *Diphyllobothrium latum*.

CHAPTER XVII

CLASS TREMATODA

I. *Characteristics of the Class*

All of the trematodes show marked modifications from their free-living relatives, the TURBELLARIA. There is an extreme development in the organs of attachment and reproduction and a reduction or loss in the sensory apparatus, organs of locomotion, alimentary system or other structures usually present in free-living flatworms. This simplicity of structure of the TREMATODA is not a primitive simplicity but is the sign of specialization as a consequence of the development of the parasitic habit. Material for a general study of trematode morphology may be readily obtained from the lungs of frogs which are usually infected with flukes of the genus *Pneumonœces*, (Figure 71). These flukes are more or less transparent and the principal structures can be readily determined in the living organism. Detailed studies on the histology and the relation of the various organs may be made from in toto mounts and serial sections.

I. EXTERNAL ANATOMY

The trematodes usually present a flattened, leaf-shaped or tongue-shaped body, or they may be barrel-shaped, conical, or attenuated (Figure 72). Most forms are small, ranging from about 1 mm. to 2 cm. or 3 cm. in length. Suckers, which may or may not be equipped with spines or hooks, are always present and vary in size and position according to the species. The ventral surface is marked by the opening of the genital pore which is usually located near the anterior border of the ventral sucker, the acetabulum. The anterior end is indicated by the oral opening which is surrounded by a sucker, the oral sucker. The excretory pore in endoparasitic forms is usually located at the posterior tip of the body; and a fourth external opening, microscopic in size, may also be present, located usually on the mid-dorsal surface. This pore is the opening of a small canal, Laurer's canal, which connects with the female reproductive system.

In ectoparasitic trematodes, the excretory system opens right and left at the anterior end of the dorsal surface.

2. INTEGUMENT

Unlike the TURBELLARIA, the adult trematodes have no epithelium. The body is covered by a non-cellular, homogeneous layer, the cuticula, which is frequently supplied with spines. The cuticula is secreted by special cells which lie embedded in the underlying tissue.

3. MUSCULAR SYSTEM

Three distinct layers of muscles lie almost directly under the cuticula. These muscles consist of the outer circular muscles, a middle, thin layer of diagonal muscles and a third, or innermost layer of longitudinal muscles. These three sets of muscles make up what is termed the dermo-muscular sac and are used in producing alterations in the form of the body. Dorso-ventral muscles traverse the body from one surface to the other. The fibers of this set of muscles possess diverging brush-like ends which are attached to the inner surface of the cuticula. The suckers are muscular organs of attachment and are provided with special sets of muscles of equatorial, radial and [illegible]al fibers. These muscles, partic[illegible] radial fibers, are well developed [illegible] powerful sucking, cup-shaped discs by which the parasite fastens itself to its host.

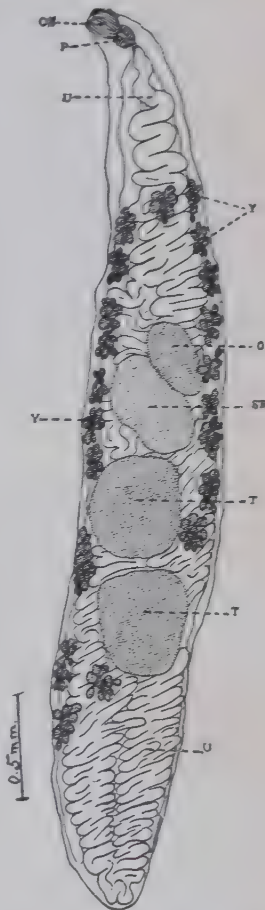


FIG. 71.—*Pneumonœces medioplexus*, dorsal view. *o.*, ovary; *os.*, oral sucker; *p.*, pharynx; *sr.*, seminal receptacle; *t.*, testis; *u.*, uterus; *v.*, vitellaria. (After Cort)

4. PARENCHYMA

All of the space between the muscles and the various system of organs is filled with a peculiar connective tissue consisting of a

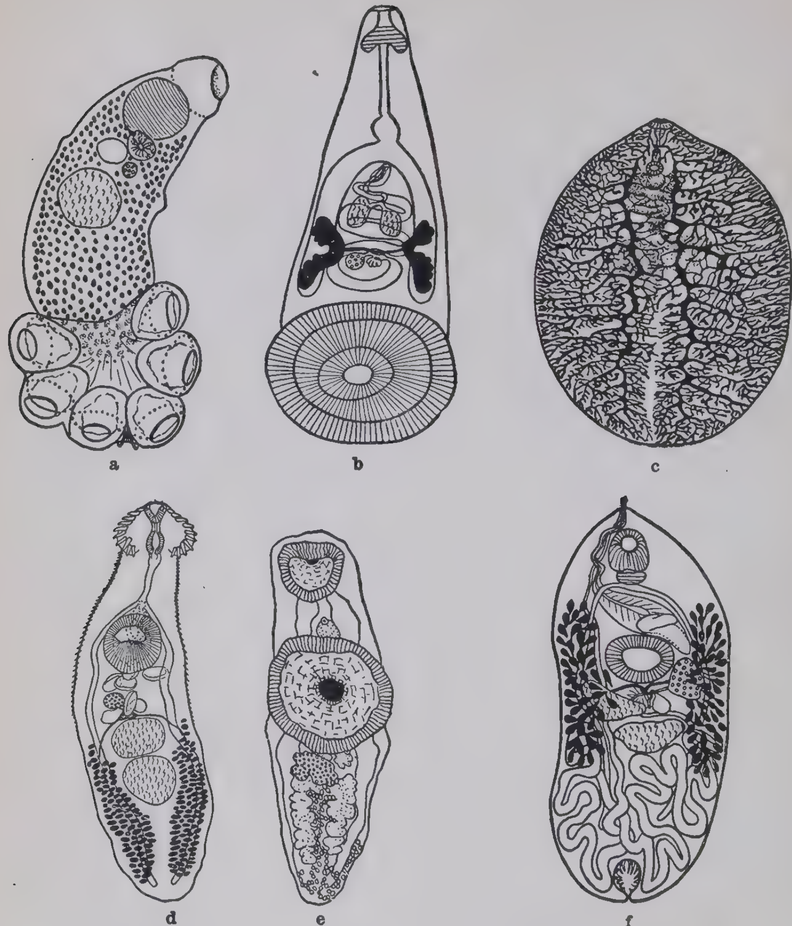


FIG. 72.—Types of adult trematodes.
a. *Polystoma megacotyle.* Mouth cavity of turtles. (After Stunkard)
b. *Diplodiscus temperatus.* Rectum of various frogs. (After Cary)
c. *Fascioloides magna.* Liver of sheep. (After Ward)
d. *Stephanoprora gilberti.* Intestine of water birds. (After Ward)
e. *Gorgodera minima.* Bladder of frogs. (After Cort)
f. *Cephalogonimus vescaudus.* Intestine of soft-shelled turtles. (After Nickerson) (Reprinted by permission from *Fresh Water Biology* by Ward and Whipple, published by John Wiley & Sons, Inc.)

network of fibers which enclose spaces filled with fluid and contain many nuclei (Figure 73). This tissue is called parenchyma and is a mesenchyme. It is a characteristic of all the flatworms. There is no body cavity.

5. DIGESTIVE SYSTEM

The digestive system commences at the tip of the worm with the mouth, which is surrounded by the oral sucker. It is generally terminal or slightly sub-terminal. From the mouth the oral cavity leads backward into a muscular pharynx which is more or less globular and is usually smaller than the oral sucker. A short pre-pharynx may appear in some cases between the oral sucker and the muscular pharynx. Usually a very short, thin tube with muscular walls, the esophagus, connects the pharynx with the intestine. These structures of the so-called "fore-gut" are lined by a continuation of the cuticula surrounding the body. Unicellular, salivary glands are present and are located above the esophagus. These glands discharge by means of long ducts into the pharynx and the esophagus. The esophagus opens into the intestine which consists of two blind crura running backward and vary in length according to the species. The intestinal crura are lined with tall cylindrical epithelium and have a weakly developed muscular layer composed of longitudinal and circular fibers. As there is no anal opening to this system, the waste products are discharged from the intestine through the oral opening which functions as both mouth and anus. The food of trematodes may consist of mucus, epithelial cells, intestinal contents of the host, blood, or secretions from the mucosa of the bile ducts, according to the position of the worm within the host and to the species of worm.

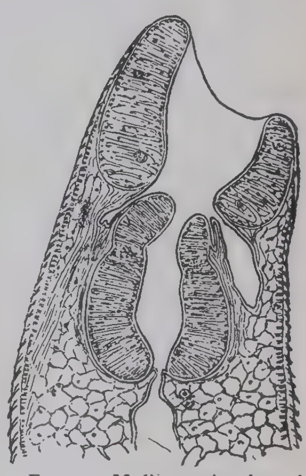


FIG. 73.—Median section through the anterior part of *Fasciola hepatica,* showing the musculature of the oral sucker and pharynx, the pharyngeal pouches, cuticula with spines and the body parenchyma. (From Fantham, Stephens and Theobold, *Animal Parasites of Man*)

6. EXCRETORY SYSTEM

The excretory system of the trematodes is a definite tubular apparatus, symmetrically developed, and consists of the following parts: (1) a bladder, (2) collecting tubes, (3) capillaries, extensions of the flame cells, and (4) numerous, scattered flame cells (Figure 74). The bladder of endoparasitic forms usually occupies the median line of the posterior quarter of the body and opens to the exterior by a small pore at the posterior

extremity, somewhat sub-terminal on the ventral surface. This pore is controlled by a sphincter muscle. The tubes of the bladder branch off at its anterior portion into the small collecting tubes and further branch off into smaller tubes which unite with the capillaries of the flame cells. The flame cell is a relatively large, hollow cell with a tuft of cilia projecting into the cavity toward the capillary (Figure 75). This tuft of cilia beats constantly during life and thus takes up the liquid waste products from the surrounding parenchyma which are then excreted by means of the capillaries, tubes and bladder.

No circulatory or respiratory system is present.

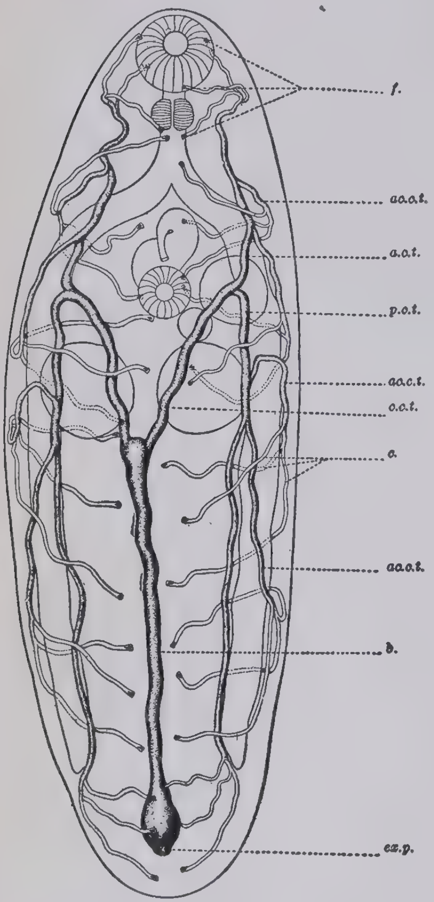


FIG. 74.—Excretory system of *Margeana californiensis*. *ac.c.t.*, accessory collecting tube; *a.c.t.*, anterior collecting tube; *b.*, bladder; *c.*, capillaries; *c.c.t.*, common collecting tube; *ex.p.*, excretory pore; *f.*, flame cells; *p.c.t.*, posterior collecting tube. (After Cort)

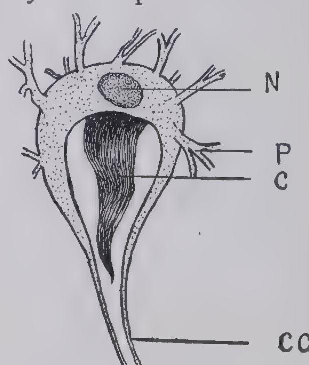


FIG. 75.—Terminal flame cell of the excretory system. N, nucleus of cell; P, process of cell connecting with parenchyma; C, bundle of cilia which forms the "flame"; CC, collecting capillaries.

7. NERVOUS SYSTEM

The nervous system usually consists of a pair of cerebral ganglia situated to the right and left of and above the pharynx. These

ganglia are connected with each other by a commissure dorsal to the pharynx, and from each ganglion three anterior and three posterior longitudinal nerves arise. The six nerves running backward are connected by numerous transverse commissures. Two of these six nerves are ventral, two dorsal and two lateral. Organs of special sense are lacking in adult endoparasitic forms but may be present in a few ectoparasitic forms and in the free-swimming stages of endoparasitic forms.

8. REPRODUCTIVE SYSTEMS

Most trematodes are true hermaphrodites, and contain complete organs of both sexes. A few, the SCHISTOSOMATIDÆ, are unisexual. The reproductive system is extremely developed, often exceedingly complicated, and the most conspicuous part of the worm. The sexual organs usually lie within the central field which is limited by the two intestinal crura. The lateral fields lie external to the intestinal crura.

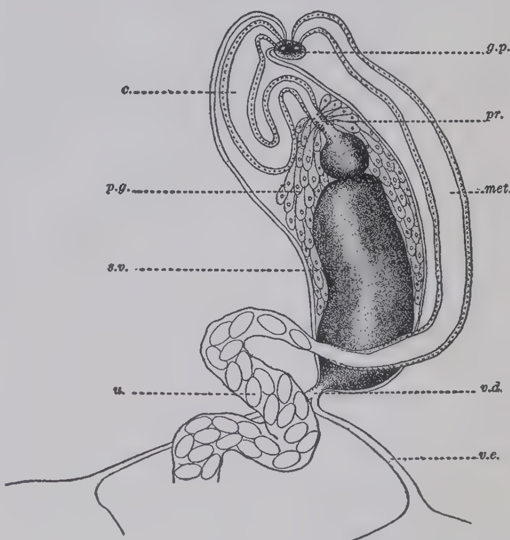


FIG. 76.—End ducts of the reproductive systems of *Margeana californiensis*; *c.*, cirrus; *g.p.*, genital pore; *met.*, metraterm; *p.g.*, prostate glands; *pr.*, prostate region; *s.v.*, seminal vesicle; *v.d.*, vas deferens; *v.e.*, vas efferens; *u.*, uterus. (After Cort)

The male genital system consists of two testes, their ducts and an organ for copulation (Figure 76). The testes are usually located in the posterior half of the body within the central field. They may lie side by side or one in front of the other and may be spherical, globular, lobed, branched or ramified, according to the species. From each testis a vas efferens originates and passes anteriorly to form, sooner or later, the vas deferens which connects with the so-called "cirrus sac." The cirrus sac is composed of three sections, (1) a dilated portion, the seminal vesicle, (2) the median section of unicellular

prostate glands, and (3) the terminal muscular portion, the cirrus, which functions as the male organ of copulation. When functioning the cirrus may be protruded through the male genital pore, through the common genital atrium and into the female system by the evagination of its lumen during the contractions of the muscular walls of the cirrus sac.

The female genital apparatus consists of a single ovary, its oviduct, a seminal receptacle, two vitelline or yolk glands with their

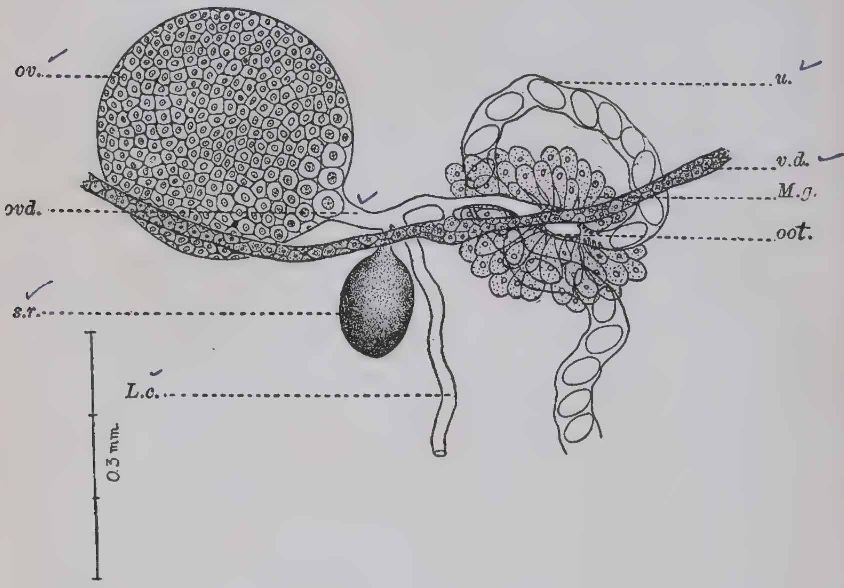


FIG. 77.—Connections of the ducts of the female reproductive system of *Margeana californiensis; L.c.*, Laurer's canal; *M.g.*, Mehlis' gland; *oot.*, oötype; *ov.*, ovary; *ovd.* oviduct; *sr.*, seminal receptacle; *u.*, uterus; *v.d.*, vitelline duct. (After Cort)

ducts, Mehlis' gland, and uterus (Figure 77). In many of the endoparasitic trematodes the female system is equipped with an additional canal, Laurer's canal, which leaves the oviduct near its union with the duct from the seminal receptacle and passes forward, opening on the dorsal surface of the body. In ectoparasitic forms, a similar canal, vitelline-intestinal canal, is found, but it leads to the intestine and not to the exterior. The ovary usually lies anterior to the testes. It is smaller than the testes and may also vary in form according to the species. It is thin-walled, vesicular in structure and contains unfertilized ova in different stages of development. The oviduct is usually very short and is soon joined by Laurer's canal and the duct

from the seminal receptacle. The function of Laurer's canal is not well understood. Its main purpose may be for an escape of excess amounts of sperm and yolk material. The seminal receptacle is a thin-walled sac-like organ and its function is the storage of the spermatozoa. Two yolk glands (vitellaria) are situated usually within the middle third of the body along each lateral field. These glands occur in grape-like bunches and are connected with each other by longitudinal excretory ducts which are connected with transverse ducts where they unite to form a common vitelline duct. The transverse ducts are ventral to the intestinal crura and usually pass somewhat below the ovary. At the union of the two transverse vitelline ducts a dilatation may occur which serves as a vitelline reservoir. The common vitelline duct joins the oviduct near the entrance of the duct from the seminal receptacle. Slightly beyond the point where the common vitelline duct joins the oviduct the tube may become considerably widened into a muscular portion known as the "oötype." The oötype is in turn surrounded by a number of unicellular glands (Mehlis' gland) which probably secrete a liquid in which the ova are suspended. The beginning of the uterus follows the oötype. The uterus of the adult endoparasitic trematodes is very long and follows an exceedingly tortuous course between the intestinal crura. It usually contains an enormous accumulation of ova and these more or less completely obscure all other organs. The terminal portion of the uterus usually lies beside the cirrus sac and discharges into the common genital atrium, which in turn opens to the exterior through the common genital pore. The very terminal portion of the uterus is often modified, and is known as the metraterm. It serves as a vagina.

9. FERTILIZATION

Both cross and self-fertilization are possible with the trematodes, although it is believed that self-fertilization is the commoner occurrence, especially among the endoparasitic forms. In both, the cirrus is the organ of copulation. Cross fertilization via Laurer's canal is possible and probably occurs from time to time. The spermatozoa, which are structurally similar to those of other animals, on entering the metraterm of the female system travel all the length of the uterus until they reach the seminal receptacle, in which they become stored up in great quantities. The ova, produced in the ovary, pass down the oviduct and become fertilized by the sperm as they pass by the opening of the duct of the seminal receptacle. Yolk

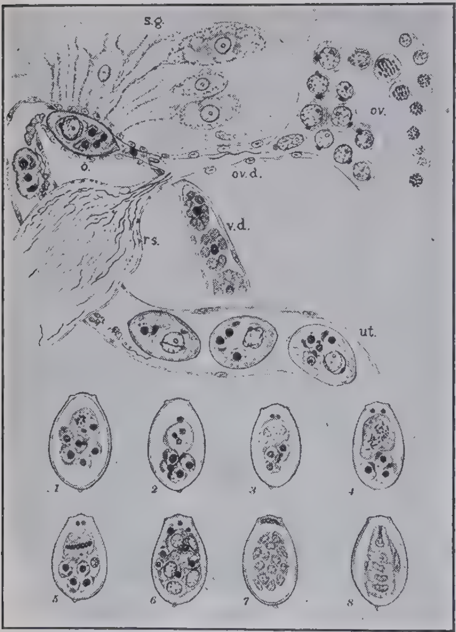


FIG. 78.—The development and fertilization of the egg in *Collyrichum faba* from the European sparrow. The cells are drawn to scale, but other structures are foreshortened and brought into one plane; *ov.*, ovary, with small, primitive ova at the periphery to the right; passing to left successive stages of development are shown—the rearrangement of the chromatin in chromosomes, the increase in the size of the ova, and the appearance of an extranuclear body, or attraction sphere, with the return of the nucleus to the resting state; *ov.d.*, oviduct in which the ova are mingled with the spermatozoa which pass from *r.s.*, receptaculum seminis; *v.d.*, vitelline duct filled with yolk cells with globules of granular material, which is liberated from these cells as they pass out of the duct; *s.g.*, Mehlis' gland—shown only in part—with secreting cells, showing cytoplasmic granules which are distributed along slender processes, extending to the oötype; *o.*, oötype, showing a peripheral membrane, enclosing a fertilized ovum, with spermatozoön coiled around the nucleus, and four yolk cells, from which the stored material has been liberated to be utilized in the formation of the shell; *ut.*, the first portion of the uterus, containing several eggs, in which the yolk material has not yet been wholly incorporated into the shell. Masses of excess yolk and occasional spermatozoa are also shown. 1-8, successive stages in the development of the egg. 8, egg containing fully developed miracidium as it leaves the parent worm. (After Tyzzer)

cells are also poured into the oviduct from the vitelline ducts. The fertilized ovum, together with a more or less constant number of yolk cells, passes into the oötype at one time and there becomes enclosed in a shell. The shape of the egg is largely determined by the oötype which contracts energetically and serves more or less as a mold. Most trematode ova have operculated shells and may possess a characteristic knob or abbreviated spine which represents a slight projection of shell material into the oviduct. The shell is probably derived from the fusing together of liberated yolk granules, while the glands surrounding the oötype probably secrete a liquid in which the ova are suspended, serving more or less as a lubricant. The completed ovum is pushed forward into the uterus followed by other ova until the uterus is completely filled. Their escape to the exterior is via the metraterm into the common genital atrium and thence to the outside through the common genital pore. The endoparasitic trematodes produce immense numbers of ova which is an adaptation to the parasitic habit, and which counterbalances the loss incurred by the species in its transfer to new hosts.

This early development of the trematodes is well illustrated in Figure 78.

10. LARVAL DEVELOPMENT

All the ectoparasitic trematodes have a simple and direct manner of development. A ciliated larva develops within the ovum, which, upon hatching, swims about in the water until it attaches itself to its host where it feeds and grows directly into the adult stage. The endoparasitic forms, on the other hand, may have an extremely

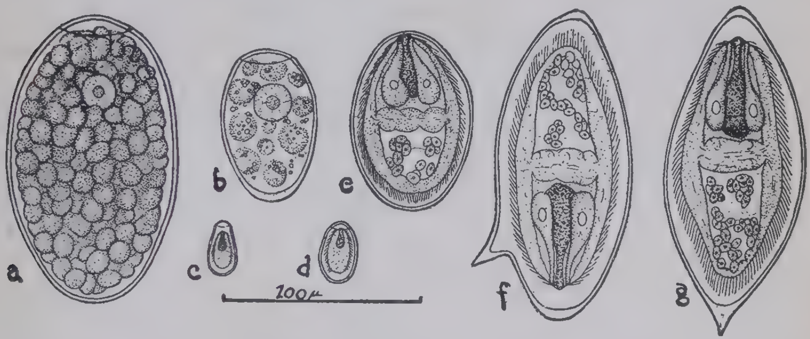


FIG. 79.—Eggs of various human trematodes. a, *Fasciolopis buski;* b, *Paragonimus westermani;* c, *Clonorchis sinensis;* d, *Metagonimus yokogawai;* e, *Schistosoma japonicum;* f, *Schistosoma mansoni;* g, *Schistosoma hæmatobium.* (After Cort) (Courtesy of The Macmillan Co.)

complicated life-cycle, involving both an alternation of generations and an alternation of hosts. There is also a multiplication by the production of both fertilized ova by the adult worm, and by a generation arising from germ cells without fertilization which takes place when the fluke is harbored by the intermediate host.

The ova of many endoparasitic forms are completely developed at the time they reach the external world, while others may show no advancement whatever (Figure 79). The ovum upon falling in fresh water may directly hatch or complete its embryological development, as the case may be. The embryo within the egg shell sooner or later escapes as a ciliated larva and swims about in search of a new host, a mollusc, which serves as its intermediate host. This larva is called the miracidium and may possess all the following structures: (1) a ciliated ectoderm with spine; (2) an elementary digestive organ (3) secretory gland; (4) a collection of germinal cells attached to the body wall or lying freely within the body; (5) an

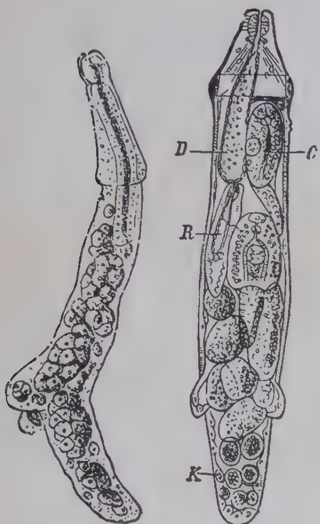
excretory system; and (6) a nervous system (Figure 80, a). The miracidium is not a feeding stage. Its function is merely to carry the infection to the snail host, and unless it finds this host within a few hours, it dies. The miracidium usually enters its host by directly penetrating through the soft tissues and in so doing becomes denuded of its ciliated ectoderm. It then becomes an irregular, sac-like, extremely simple organism termed the sporocyst (Figure 80, b and c).

FIG. 80.—Development of redia within the sporocyst. *Fasciola hepatica. a,* miracidium, a ciliated, free-swimming larva containing germ balls, two flame cells, one below each of the larger germ balls, and an X-shaped eye-spot; *b,* young sporocyst with two eye-spots, and germ balls; *c,* older sporocyst with young redia and undifferentiated germ balls. Magnified. (From Fantham, Stephens and Theobald, *Animal Parasites of Man.* After Leuckart)

The sporocyst possesses a body cavity which serves as a brood pouch for the developing daughter embryos. The daughter embryos grow to maturity and escape from the mother sporocyst by the rupture of the wall, and in turn, produce young parthenogenetically. This generation may also consist of simple organisms, sporocysts, which by a similar process give rise to larval trematodes, cercariæ; or they may consist of organisms, which are termed rediæ, possessing a rhabdocœle intestine with pharynx, an oral sucker and a birth pore (Figure 81). A granddaughter generation follows which may consist of cercariæ or another generation of rediæ which in turn gives rise to a generation of cercariæ. The cercariæ are a still more differentiated organism than the rediæ, showing both oral and ventral suckers, mouth, pharynx and bifurcated intestine, excretory system, specialized glands and a caudal appendage by which it propels itself through the water (Figures 82 and 83).

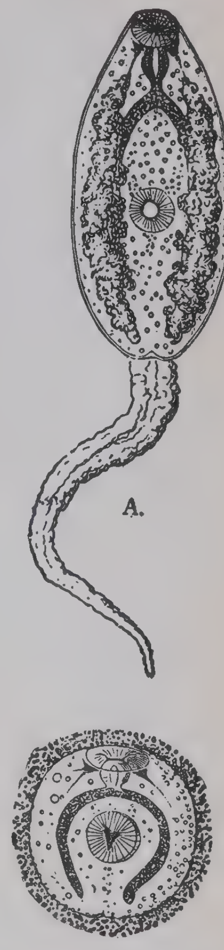
The cercariæ leave the molluscan host. Their function is to reach a suitable vertebrate host, the primary host, for the completion of the life-cycle of the species to the adult stage. Entrance is gained into this host either by the cercariæ actively penetrating the host's

tissues or by being taken in with the food of the host. In the first case, the cercariæ are equipped with a well developed secretory apparatus for attacking and penetrating the tissues of the mammalian host. In the second case, the cercariæ may become encysted on vegetables which serve as food for the mammalian host, or they may penetrate into a lower vertebrate (fish) or an arthropod (crayfish, crabs, or the like) which in turn become food for the definitive host. Such cercariæ possess special cystogenous glands which not only secrete substances for their attachment to infective agents, vegetables, and so on, but also for the impermeable substances which surround the cercariæ, the true cyst wall. The true cyst wall protects the cercariæ against unfavorable conditions of the environment and against the acid medium of the stomach of the vertebrate host. The encysted stage of trematodes is generally termed the metacercaria. It is also known as the adolescaria. The cercariæ of some species encyst in the molluscan host within the sporocyst itself instead of swarming out as in other cases. In every case, the



A. B.

Fig. 81.—Development of cercariæ within the rediæ. *Fasciola hepatica.* A., young rediæ, showing pharynx and rudimentary intestine; B., older rediæ: *D,* intestine; *C,* cercariæ; *K,* germ balls; *R,* redia. Magnified. (After Leuckart)



B.

Fig. 82.—A. Cercaria of *Fasciola hepatica,* a free-swimming larva, showing oral and ventral sucker and rudimentary digestive system. Well developed cystogenous glands occupy the lateral borders of the body proper.

B. Encysted cercaria, or metacercaria of *F. hepatica.* Magnified. (From Fantham, Stephens and Theobald, *Animal Parasites of Man.* After Leuckart)

cercaria, free or encysted, according to the species of trematode, is the only stage which is infective to the final, vertebrate host.

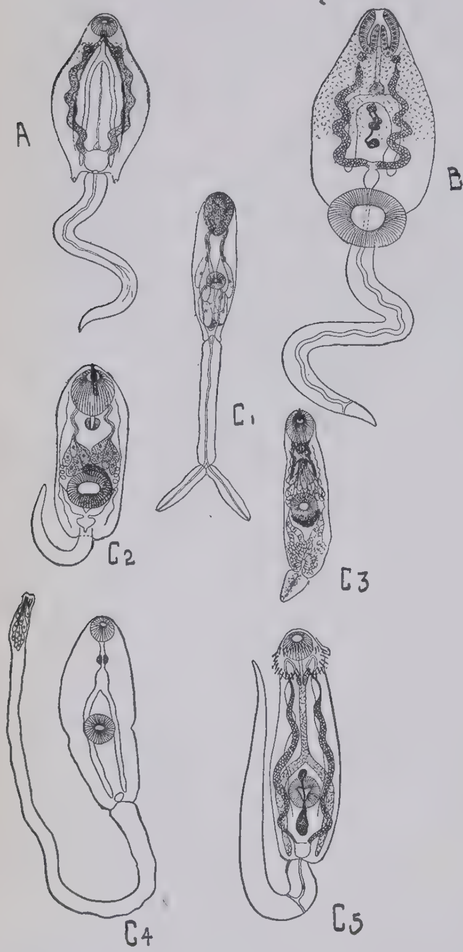


FIG. 83.—Examples of North American cercariæ: A, Monostome cercaria, *C. urbanensis.* B, Amphistome cercaria, *C. inhabilis.* C, Distome cercariæ; C1, Furcocercous, *C. douthitti;* C2, Xiphidiocercaria, *C. isocotylea;* C3, Microcercous, *C. trigonura;* C4, Gymnocephalous, *C. megalura;* C5, Echinostome, *C. trivolvis.* (After Cort)

The endoparasitic trematodes are perhaps the least specific in their hosts of all the helminths having as a rule a wide range of both definitive and intermediate hosts. *Clonorchis sinensis* in the adult stage is widely distributed in man and the cat and dog in certain parts of the Orient; and its parthenogenetic development may take place in a number of species of fresh-water snails. At least thirty-four species of fresh-water fish are known to harbor the metacercariæ of this parasite. The lung fluke, *Paragonimus westermani,* likewise shows a wide range in its hosts.

II. *Classification*

1. CLASSIFICATION OF CERCARIÆ

By placing snails from fresh-water ponds and streams into small glass receptacles and examining them closely with the unaided eye or a hand glass, small, white, exceedingly active organisms may be seen escaping from the snail. These are cercariæ and may be collected with a pipette for microscopical study. The cercariæ, as well as other developing larval stages within the body

of the snail, may also be obtained for study by cutting or crushing the shell so as to remove the body onto a glass slide for microscopic examination. If larval trematodes are present, some are almost invariably loosened from the infected part of the snail during this operation and may be found scattered around the snail in the water. The liver, or digestive gland, is apt to be the organ which is most heavily infected and may contain sporocysts, rediæ, cercariæ and even metacercariæ. These may be studied in the living condition or killed in a sublimate fixing fluid and stained with hæmatoxylin.

A careful study of the cercariæ will show that they possess both (1) "adult characters" such as suckers, digestive and excretory systems, which foreshadow adult structure, and (2) "larval characters" which are merely temporary structures, the tail, stylet, cystogenous and cephalic glands, which are not carried over into adult life, but are developed only to meet the requirements of larval conditions.

The following is a summary of Lühe's (1909) classification of cercariæ which will aid the student in their identification. The main divisions are largely based on the "adult characters" of the cercariæ, showing their relation to the recognized adult groups; while the subdivisions of the distome cercariæ are based entirely on "adaptive larval characters." Only a few of the relations of cercariæ and adult trematodes are known, however, and Lühe's classification is therefore not a natural one. Types of different cercariæ from North American molluscs are shown in Figure 83.

LÜHE'S CLASSIFICATION OF CERCARIÆ

A. Cercariæ with longitudinal projections along the sides of the body. LOPHOCERCARIÆ.

B. Two long projections from the end of the body. Mouth opening in the middle of the ventral surface. Intestine simple, sac-like. GASTEROSTOME CERCARIÆ.

C. Ventral sucker lacking. MONOSTOME CERCARIÆ.

D. Ventral sucker at the posterior end of the body. AMPHISTOME CERCARIÆ.

E. Ventral sucker some distance in front of the posterior end of the body. DISTOME CERCARIÆ. (Contains cercariæ of most of the flukes of man.)

   1. Base of tail forms a space into which the body can be drawn. CYSTOCERCOUS CERCARIÆ.
   2. Tail having as great or greater width than body. RHOPALOCERCOUS CERCARIÆ.

3. Tail straight, slender and narrower than body, without stylet or boring spine. GYMNOCEPHALUS CERCARIÆ.
4. Simple tail, bearing a stylet in oral sucker. XIPHIDIOCERCARIÆ.
5. Anterior sucker surrounded by a circlet of spines. ECHINOSTOME CERCARIÆ.
6. Tail set with spines. TRICHOCERCOUS CERCARIÆ.
7. Tail stumpy. MICROCERCOUS CERCARIÆ.
8. Tail entirely undeveloped. CERCARIÆ.
9. Tail forked at its end. FURCOCERCOUS CERCARIÆ.
10. Cercariæ grouped in bunches with individuals united by tips of tails. RATTENKÖNIGCERCARIÆ.

2. CLASSIFICATION OF ADULT TREMATODES

The class TREMATODA is divided into two large subclasses, (1) the Subclass MONOGENEA, and (2) the Subclass DIGENEA. The first group as previously stated, include external parasites possessing powerfully developed, posterior organs of attachment and have no intermediate host (Figure 72, a). Their development is direct. Such flukes are termed monogenetic trematodes. They are, for the most part, parasites on the body surface or gills of fish or on other aquatic vertebrates. The members of the second group, DIGENEA, are endoparasites and have, as earlier outlined, a development through a complex series of stages involving an alternation of hosts, one of which is always a mollusc. All of the trematodes parasitic in man as well as those of lower veterbrates having economic importance belong to DIGENEA. The species occurring in man are further limited within the subclass DIGENEA to the order PROSOSTOMATA. Their relation to other digenetic trematodes is given in the following table. The classes and orders as given by Ward and Whipple (1918) are closely followed. The student is also referred to Poche, 1926.

Class TREMATODA. PLATYHELMINTHES; living as ectoparasites or endoparasites; cilia present only in larval stage; alimentary canal present; adult stage parasitic in vertebrates.

Subclass MONOGENEA. TREMATODA; ectoparasites; posterior organs of attachment usually extremely developed with chitinous anchors and hooks; uterus short usually containing only a single ovum; development simple, direct. Parasitic on fish, terrapin and Amphibia.

Order I. MONOPISTHOCOTYLEA Odhner. MONOGENEA with ex-

cretory pores anterior, double and dorsal. The uterus is short and usually contains but a single egg. Posterior organ single; vagina unpaired and no genito-intestinal canal. Most forms are ectoparasites on body surface or gills. Example, *Ancyrocephalus* sp. on the gills of fresh-water fish.

Order 2. POLYOPISTHOCOTYLEA Odhner. MONOGENEA with posterior organs multiple (two to many parted). Vagina double; genito-intestinal canal present. Example, *Polystoma megacotyle* in the mouth cavity of turtle, *Chrysemys marginata.*

Subclass DIGENEA. TREMATODA; endoparasites; organs of attachment consisting of one or two suckers of which the anterior is always single and median; without chitinous anchors and hooks; uterus long containing great masses of ova; development by metamorphosis and alternation of hosts; all trematodes parasitic in man fall within this group.

Order I. GASTEROSTOMATA Odhner I. DIGENEA; degenerated, non-perforate anterior sucker; mouth on mid-ventral surface without oral sucker; intestine a simple sac; parasitic in fish. Example, *Bucephalus pusillus.*

Order 2. PROSOSTOMATA Odhner. DIGENEA; mouth at or near anterior tip of body and usually surrounded by an oral sucker; a second sucker, if present, behind oral sucker on ventral surface or at posterior end; all trematodes of man belong to this order.

Suborder I. ASPIDOCOTYLEA Monticelli. PROSOSTOMATA with ventral organ of attachment a powerful adhesive disc or composed of a series of small suckers; parasitic in molluscs and cold-blooded vertebrates. Example, *Aspidogaster conchicola* in UNIONIDÆ.

Suborder 2. MONOSTOMATA Zeder. PROSOSTOMATA with no ventral organ of attachment; oral sucker present; parasitic mostly in birds and reptiles. Example, *Collyriclum faba* in English sparrows.

Suborder 3. HOLOSTOMATA Lühe I. PROSOSTOMATA; special adhesive organ or holdfast behind acetabulum; body separated into distinct anterior and posterior regions; parasitic in frogs, birds and CARNIVORA. Example, *Alaria ariscæmoides* in the red fox.

TABLE IV

DISTRIBUTION, INCIDENCE AND DIAGNOSIS OF THE COMMONER AND MORE IMPORTANT TREMATODES

	Scientific Name	Development	Geographical Distribution	Incidence	Diagnosis
Intestinal Flukes	*Echinochasmus perfoliatus* var *japonicus*	Metacercariæ in fresh-water fish	Japan	Incidental in man; frequent in dog and cat	Eggs in feces
	Echinostoma ilocanum	Not known	Philippine Islands	Incidental in man	Eggs in feces
	Euparyphium malayanum	Not known	Malaya	Incidental in man	Eggs in feces
	Fasciolopsis buski	Metacercariæ on water-grown vegetables	China, Indo-China, Formosa, Sumatra, India	Frequent in man (China) Frequent in pigs (Formosa)	Eggs in feces
	Gastrodiscoides hominis	Not known	Malay States, Assam, India, Cochin-China, British Guiana	Incidental in man, frequent in pigs	Eggs in feces
	Heterophyes heterophyes	Metacercaria in musculature and peritoneum of fresh-water fish	Egypt, China, Japan	Frequent in man, cat, dog and fox in Egypt	Eggs in feces
	Heterophyes katsuradi	Metacercaria probably in fresh-water fish	Japan	Rare	Eggs in feces
	Metagonimus yokogawai	Metacercaria in fresh-water fish (trout)	Korea, China, Japan	Frequent in man, cat, and dog	Eggs in feces
	Watsonius watsoni	Not known	West Africa	Incidental in man and monkey	Eggs in feces

DISTRIBUTION, INCIDENCE, AND DIAGNOSIS OF THE COMMONER AND MORE IMPORTANT TREMATODES—(*Continued*)

Liver Flukes	*Clonorchis sinensis*	Metacercaria in fresh-water fish	China, Japan, Korea, Formosa, French Indo-China	Frequent in man, cat, dog and fish-eating mammals	Eggs in feces
	Dicrocoelium lanceatum	Unknown, metacercaria probably in fish	Europe, Siberia, Northern Africa	Frequent in herbivores, incidental in man	Eggs in feces
	Fasciola hepatica	Metacercaria on vegetation or floating on water	Cosmopolitan	Incidental in man; frequent in sheep	Eggs in feces
	Fascioloides magna	Not known, metacercaria probably on vegetation	North America	Prevalent along Gulf of Mexico	Eggs in feces
	Opisthorchis filineus	Metacercaria in fresh-water fish	East Prussia, Serbia, Annam, Philippines	Frequent in man, cat and dog	Eggs in feces
	Opisthorchis noverca	Metacercaria in fresh-water fish	India	Incidental in man, normal host, dog	Eggs in feces
	Opisthorchis viverrini	Metacercaria in fresh-water fish	Siam	Incidental in man, normal host, civet cat	Eggs in feces
Lung Flukes	*Paragonimus westermani*	Metacercaria in fresh-water crabs	Japan, Korea, Formosa, Philippine Islands, Americas	Frequent in man only in Orient, also in tiger, dog, cat and pig	Eggs in sputum, may also occur in feces
Blood Flukes	*Schistosoma hæmatobium*	Direct penetration of final host by cercaria	Africa, Near East, Portugal, Australia	Frequent in man, experimentally in rat, mouse, guinea pig and monkey	Eggs in urine; may also occur in feces
	Schistosoma mansoni	Direct penetration of final host by cercaria	Africa, West Indies, North and South America	Frequent in man, experimentally in laboratory animals	Eggs in feces
	Schistosoma japonicum	Direct penetration of final host by cercaria	Japan, China, Philippines	Frequent in man, experimentally in laboratory animals	Eggs in feces

Suborder 4. AMPHISTOMATA Nitzsch. PROSOSTOMATA; acetabulum terminal or subterminal and posterior to the reproductive organs; body often conical, tapering anteriorly, cuticle without spines; parasitic in amphibians, reptiles, birds, ruminants, rodents and mammals. Examples, *Diplodiscus temperatus* in the rectum of frogs; *Gastrodiscoides hominis* in man.

Suborder 5. DISTOMATA. PROSOSTOMATA; only oral and ventral suckers present for attachment; reproductive organs completely or largely posterior to ventral sucker; all trematodes of man except two belong to this suborder. Examples, *Pneumonœces medioplexus* in the lungs of frogs; *Fasciolopsis buski* in the intestine of man; *Schistosoma hæmatobium* in the portal system of man.

The commoner and more important trematodes of man and domestic animals are listed in Table IV (pages 212-213).

CHAPTER XVIII

THE INTESTINAL FLUKES

I. *Fasciolopsis buski* (Lankester, 1857)

Fasciolopsis buski belongs to the family FASCIOLIDÆ Railliet, 1895, characterized by their fairly large, flattened bodies and the greatly branched testes and ovary. The uterus is usually short and lies entirely anterior to the ovary.

I. HISTORICAL

Fasciolopsis buski (Figures 84 and 85) was discovered by Dr. Busk in 1843 in the duodenum of a Lascar (East Indian) sailor who died in the Seamen's Hospital in London. Lankester, in 1857, de-

FIG. 84.—*Fasciolopsis buski.* Varieties of the fluke from man. Natural size. (After Goddard)

scribed this parasite and named it *Distoma buskii.* Apparently Dr. Busk objected to this designation and the specimen was redescribed in 1860 by Cobbold who gave it the name *Distoma crassum.* This name, however, could not stand as it was already preoccupied for

another species of trematode; and further, according to the rules of zoölogical nomenclature, the original specific designation had to be accepted. In 1899 Looss carefully worked out the morphology of this parasite and created the genus *Fasciolopsis* to which it was assigned. Several species of *Fasciolopsis* have since been described from man under the names *Fasciolopsis rathouisi, F. fülleborni,* and *F. goddardi,* but Goddard (1919) brings conclusive evidence that they are all the same. Brown described in 1917 *Fasciolopsis spinifera* from China, basing the specific differences on the presence of cuticular spines. Barlow (1925) has now shown that this specific division is invalid, as it was based on differences which had been produced by different ways in which the parasites had been recovered from the patients and by the treatment they had undergone in various preservative solutions. Inasmuch as Brown was unaware of the manner his material was handled before he received it, his specific division is unwarranted and the conclusion can be drawn that there is but one species of *Fasciolopsis* in man, i.e., *Fasciolopsis buski* (Lankester).

2. DISTRIBUTION AND FREQUENCY

Fasciolopsis buski is widely spread, having been reported from many parts of China, as far north as the Yangtze Valley and as far west as Chengtu and Suifu in Szechuen province and throughout the southern provinces. It has also been reported from India, Assam, Straits Settlements, Siam, Sumatra and Borneo. It is also probable that it exists in the Philippine and Hawaiian Islands because of the great migration of Chinese to these islands. It occurs to the greatest extent in China, and there the most heavily infected endemic center is the Shaohsing area, a district of about 1,600 square miles containing between a million and a million and a half people. So prevalent is this parasite in this area that it is considered one of the principal causes of a severe illness and of a great loss of life. This area was recognized as an endemic center of fasciolopsiosis as early as 1893, and is apparently the only endemic center of this parasite in man in China and probably the only place in the world where it affords an important public health problem.

3. DESCRIPTION OF THE ADULT

Fasciolopsis buski is the largest trematode parasitic in man and may attain a length of 75 mm. and a width of 15 mm. The size of the parasites varies greatly, however, in different patients. It has

been observed that flukes from very poor people are smaller than those from patients of better financial status, indicating that the parasites thrive better on a more varied fare than the poor people provide them. Also where the infection is massive the parasites usually are smaller in size than where the infection consists of a few worms only. The largest flukes usually come from light infections. The average length is about 30 mm., average width about 12 mm. and average thickness about 2 mm. In the living condition the worms may be flesh-colored or the color of normal fresh blood, elongated, oval in outline and narrower anteriorly than posteriorly. The cuticula is covered with small, backward pointing spines arranged in transverse rows; these are most numerous about the acetabulum. The oral sucker is subterminal on the ventral side and is about 0.5 mm. in diameter. The acetabulum lies posterior and close to the oral sucker; it is from two to three times as large as the oral sucker, and has a pear-shaped opening. The prepharynx leads into the pharynx and there is practically no esophagus. The intestinal crura branch off almost directly from the pharynx and pass to the posterior extremity with two characteristic curves, one at the anterior border of the anterior testis, the other between the testes.

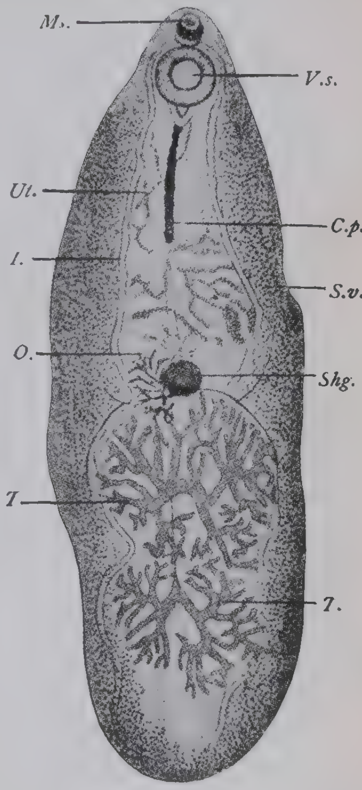


FIG. 85.—*Fasciolopsis buski.* Showing detail of anatomy: *V.s.*, ventral sucker; *C.p.*, cirrus pouch; *I.*, intestinal crura; *S.v.*, vitellaria; *T.*, testes; *O.*, ovary; *Ms.*, sucker; *Shg.*, Mehlis' gland; *Ut.*, uterus. Magnified. (From Fantham, Stephens, and Theobald, *Animal Parasites of Man.* After Odhner)

4. MALE GENITAL SYSTEM

The testes occupy the posterior half of the body within the central field and lie one behind the other. They are dichotomously

branched and their ducts unite in the middle portion of the anterior half of the body to form a seminal vesicle which passes forward as a convoluted tube within the cirrus sac which opens into the genital atrium, the pore of which opens immediately anterior to the acetabulum on the ventral surface.

5. FEMALE GENITAL SYSTEM

The ovary is also branched and is situated in the middle of the body on the right of the median line. Mehlis' gland is well developed

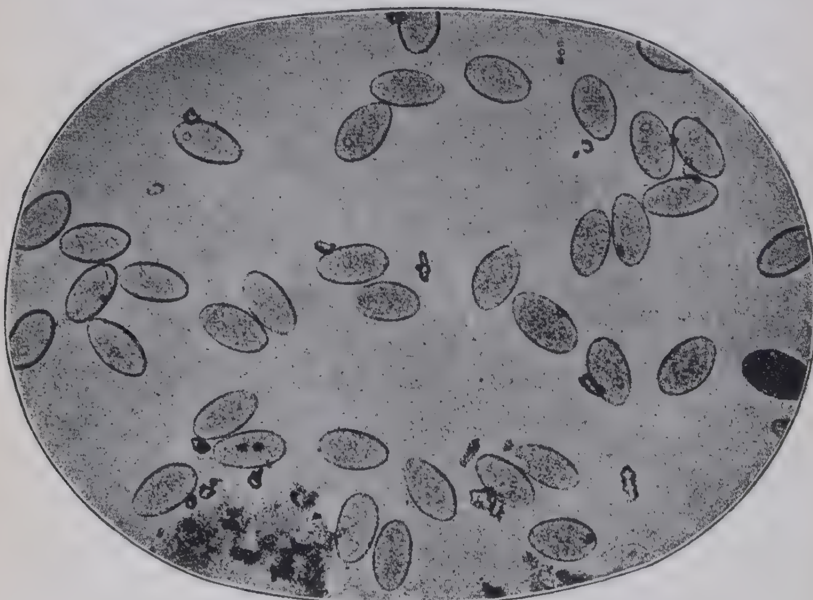


FIG. 86.—*Fasciolopsis buski*. Ova from feces (x 68). (After Goddard)

and is placed immediately to the left of the ovary. The vitellaria extend from the acetabulum along the lateral fields to the posterior tip of the body where they meet. The acini are very small. The uterus lies entirely anterior to the ovary and testes and is relatively short in comparison with that structure in many other trematodes. The eggs are usually very numerous in the feces from persons harboring the infection and in very light infections it is almost impossible to overlook them by simple methods of examination. They average 138 μ in length and 83 μ in breadth, and show no develop-

ment when found in freshly passed feces (Figure 86). They are predominately oval in outline, brown in color, and are closed by a very delicate operculum.

6. POSITION IN THE HOST

Fasciolopsis buski lives normally in the small intestine and to some extent in the stomach of man and pig. In the endemic areas of China, the Shaohsing area in Chekiang Province, from 40 per cent to 50 per cent of the hospital patients harbor this parasite, and in some villages, 100 per cent have been found infected. Elsewhere in China it is found in a very small percentage of the population. In Formosa the infection is very common among pigs, but is not prevalent in the human population. In the Shaohsing area, however, the reverse situation has been found. This fact suggests a possible physiological difference between the human and pig form although sufficient evidence is lacking to decide this question.

7. LIFE-CYCLE

The development of *Fasciolopsis buski* closely parallels that of *Fasciola hepatica,* the sheep liver fluke, which has served for so many years as a classical illustration of the development of digenetic trematodes. Nakagawa (1921) worked out the life history of *Fasciolopsis buski* from pigs in Formosa, and Barlow (1925) followed the development in detail from human material in the Shaohsing area, China. (See Figure 87.)

The egg of *Fasciolopsis buski* is usually oval in outline although many variations may occur in a given infection as well as among ova from the uterus of a single fluke. Barlow (1925) made measurements of 1000 ova from ten different sources which gave an average size of $138\,\mu \times 83\,\mu$. The maximum size was $181\,\mu \times 95\,\mu$ and the minimum size $67\,\mu \times 43\,\mu$. They may be nearly colorless, or may have a faint tinge of yellow or again they may be a dark yellowish-brown color. This change in color is attributed to differences in diet of different individuals. In a rich protein diet the color of the ova is quite dark while in a strictly vegetable diet they take on a pale-yellowish color. The shell is thin and transparent and the operculum, which is attached to one point, is sealed around its circumference with a substance which is resistant to outside influences but is apparently dissolved by the secretions of the head glands at the time of maturity of the miracidium. The ova when passed are in the one

or two-celled stage and are surrounded by from twenty to forty yolk balls which disappear as the ovum develops. At the opercular end of the egg is a mucoid plug which probably acts as a protection against too early loosening of the operculum by the secretion of the miracidium.

Development among a given lot of ova is uneven, some may show little or no advancement while in others the miracidia may be escaping from the shells. Usually at least twenty-two days are required for the miracidium to mature at optimum temperature, from 80° to 90° F. The fully developed miracidium within the shell is covered with a ciliated ectoderm composed of five tiers of six plates to the tier. There is present a well defined, pigmented eye-spot and two flame cells. The miracidium also possesses a primitive digestive tract, a cul de sac, the mouth of which is patent. At the time of the escape of the miracidium from the shell the operculum is instantaneously opened following the dissolution of the mucoid plug by secretions of the miracidium and the miracidium swims away seeking a suitable host. The span of life of the free-swimming miracidium is limited to only a few hours unless it reaches and successfully enters its snail host, *Planorbis schmackeri* or *Segmentina nitedellus.*

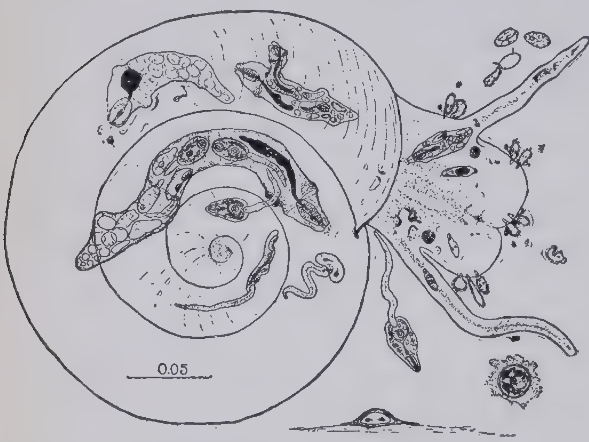


FIG. 87.—*Fasciolopsis buski.* Showing diagramatically the complete life-cycle. (After Barlow)

The miracidium may enter the snail hosts either through the respiratory orifice and then into the respiratory chamber where they enter directly into the body of the snail through the epithelial lining of the chamber, or they may actively penetrate any projecting surface of the snail. During the intrusion of its body into the tissues of the snail, the ectodermal plates become lost and the miracidium becomes the sporocyst. The development of the mother rediæ within the sporocyst is rapid. They emerge in about nine days and migrate up

to the ovotestis of the snail. These mother rediæ produce daughter rediæ and the daughter rediæ in turn give rise to cercariæ. The cercariæ begin to emerge from the daughter rediæ in about twenty-five to thirty days after the infection of the snail by the miracidium, and, after leaving the daughter rediæ, they remain in the liver region for some time to mature before their migration down the lymph spaces to an exit from the snail.

The cercaria of *Fasciolopsis* is of the leptocercous type, possessing a straight, slender tail. It possesses two groups of well developed cystogenous glands, which later take part in the formation of the cyst. One set, the round-celled glands, secretes the material for the outer cyst wall and lies dorsally, and the other set, the rhabdoidal glands, secretes the material for the inner cyst wall. The free-swimming stage is brief and occupies only time enough for the cercaria to reach a plant where it attaches itself with its mouth and ventral suckers and begins to encyst. The outer cyst wall is formed first. This wall is well adapted to its purpose of acting as a simple supportive case for the cyst. It is extremely friable and easily detached from the plant. The inner cyst wall, however, is thick and tough. It is resistant even to hydrochloric acid, but is soluble in the intestinal juices. The cysts are more or less spherical; the outer cyst wall averages about $216\,\mu \times 187\,\mu$, while the inner cyst wall averages $148\,\mu \times 138\,\mu$.

Barlow found that the snails, from which the cercariæ have escaped, usually feed on water nuts, caltrop (*Trapa natans* and *Eliochairs tuberosa*), which vegetables are used as food by the human population of the endemic areas. The crops are fertilized with human feces and are raised in field-enclosed ponds. The ova of the parasite are thus directly introduced into the habitat of the snail host and the relationship between the snail and the plant brings the encystment of the cercaria to the place where it is most efficacious for the parasite and most dangerous for man.

These water nuts or caltrops are brought into the Chinese markets by the middle of July and until the end of September for sale as fresh nuts. After this until the next spring they are sold as dry or stored nuts. As drying quickly kills the metacercariæ, it is only the fresh nuts that are of any danger. The danger of infection in the market is greatly enhanced because the vendor constantly sprinkles the caltrops with a brush dipped into unboiled canal water. Most of the caltrops are eaten raw at the time of purchasing, while those eaten in the fields are taken directly from the water where they grow just below the surface of the water on flesh root stalks. They are

peeled with the teeth, during which process the outer cyst wall becomes ruptured and the cyst is deposited into the mouth and passes on to the duodenum. Here the inner cyst wall is dissolved away and the immature worm attaches itself to the mucosa of the upper intestine and rapidly grows into the adult stage. Barlow has found as many as 200 cysts of *Fasciolopsis buski* on a single caltrop. It is not surprising therefore that exceedingly heavy infections often occur in man in the endemic area.

8. PREVENTION AND CONTROL

The measures for prevention and control of fasciolopsiasis are, as in most cases of endemic helminth diseases, simple in theory and exceedingly difficult to carry out in actual practice. They involve the changing of age-old customs, laws and religions of people who are, as a rule, ignorant, suspicious, more or less indifferent and superstitious. The control of human fasciolopsiasis is however hopeful, because it seriously affects only the people of a relatively small, limited area, the life history of the parasite is thoroughly understood, and the diagnosis of infected individuals is easily made from the ova, which are large and occur in large numbers, even in very light infections. A number of efficient and cheap drugs are also known which readily expel the adults from the host. Free clinics within the endemic area together with educational propaganda have already resulted in noticeable improvement clinically in some localities.

Time-honored customs within the endemic area are, however, particularly favorable for the propagation of the life-cycle of *Fasciolopsis buski.* Fresh human excrement, urine and feces, is used for the fertilization of the caltrop crop. The farmers row their boats to the towns, buy the fresh night-soil at the door from housewives who have a few days' accumulation stored in large wooden pails. These boat-loads of fresh feces-urine are taken directly to their fields, diluted well with water and then applied, untreated, to the fields. There are also those who run public conveniences for a livelihood, placing them along the traveled roads for the use of the passing public. The fertilizer from such sources is more likely to be infected because these conveniences are patronized largely by persons afflicted with some intestinal disease, which makes it impossible for them to wait until they get home where they might defecate in their own receptacle thereby retaining possession of a saleable article. The farmer who buys from such sources thus brings the infection to his

fields and it is he and his family who are often most heavily infected.

The free-living stages of *Fasciolopsis* as well as the snail hosts are sensitive, non-resistant organisms and are easily destroyed by several methods. The ova of the parasite are quickly killed in unslaked lime, even in dilutions of 1 : 1000. This dilution is also effective against the free-swimming stages and the snail hosts. The ova may also be destroyed by storing the night-soil, drying the feces, or exposing it to natural enemies, freezing and heating. Storage of the feces is perhaps the most desirable method and is the method used by farmers who can afford it. Fresh feces are used for fertilizer largely by the poorer farmers. To what extent the pig serves as a reservoir for human infection is at present questionable. If, however, the pig is dangerous, its habits could easily be controlled.

II. *Heterophyes heterophyes* (von Siebold, 1852)

This species belongs to the family HETEROPHYIDÆ Odhner, 1914. This family consists of very small trematodes having a pseudo-sucker surrounding the genital pore. The ovary lies in front of the testes which are usually globular or oval in outline. Other representative genera of this family are *Metagonimus, Stamnosoma* and *Monorchotrema.*

I. HISTORICAL

Heterophyes heterophyes was first discovered in 1851 by Bilharz in the intestine of a boy who died in Cairo, Egypt. A year later it was named *Distoma heterophyes* by von Siebold. Cobbold, in 1866, created the genus *Heterophyes* and made this worm a type for his new genus. The name *Heterophyes heterophyes* was applied in 1900 by Stiles and Hassall, according to the rules of zoölogical nomenclature. A second case of this infection was not made until almost forty years later by Blanchard (1891) and it appeared as though the incidence might be very light. Looss (1896), however, reported three cases in Egypt, two at autopsies and the third from a fecal examination and later concluded that this parasite occurred commonly in man in Egypt and that many cases escaped notice in fecal examinations due to the small size of the ovum.

Leiper (1913) found two cases which were diagnosed as infections with *Heterophyes heterophyes* in the Seamen's Hospital in London, one in a Chinaman and the other in a Japanese. In one case, 200 worms were obtained. O'Connor (1919) reported this parasite in two white soldiers who had been in Egypt for only a

short time. Onji in 1910 found a peculiar type of distome ovum in human feces in the Yamaguchi Province, Japan, which he thought might be the ova of *Clonorchis*. He later found an encysted cercaria in the muscles of a fresh-water fish, *Mugil japonicus*, which is eaten raw by the people of that district. Together with Nishio, he described (1915) the adult form under the name *Heterophyes nocens*, and gave an account of its life history. The characters given for this parasite are almost identical with those of *Heterophyes heterophyes* so that it is probable that they are one and the same species.

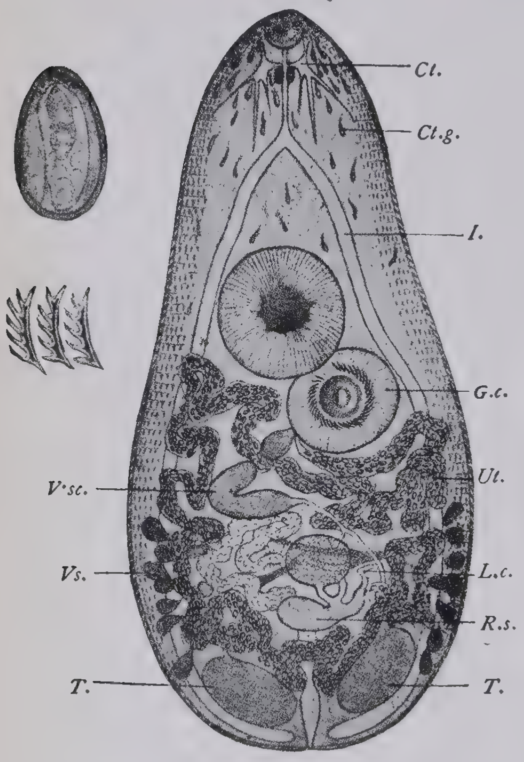


FIG. 88.—*Heterophyes heterophyes. Ct.,* cerebral ganglia; *I.,* intestinal crura; *Ct.g.,* cuticular glands; *V.sc.,* vitellaria; *Ut.,* genital sucker; *T.,* testes—the excretory bladder between them; *L.c.,* Laurer's canal; *R.s.,* seminal receptable with the ovary in front of it; *G.c.,* genital sucker; *V.s.,* seminal vesicle, 53/1. On the left side above, an egg, 700/1, is depicted, and below it three rodlets from the genital sucker, 700/1. (From Fantham, Stephens and Theobald, *Animal Parasites of Man.* After Looss)

2. DISTRIBUTION AND FREQUENCY

Heterophyes heterophyes is probably relatively frequent in man in Egypt. In that country it is very common in the cat and dog and probably also in the fox. It has also been reported in man and dogs from China and Japan.

3. DESCRIPTION OF THE ADULT

Heterophyes heterophyes (Figure 88) is a very small trematode measuring from 1 mm. to 1.7 mm. in length by 0.3 mm. to 0.7 mm.

in breadth. It has an oval, elongate shape and is gray in color when passed in fresh feces; a brown spot marking the position of the uterus is visible on the mid-ventral surface. The ventral sucker is located immediately in front of the middle of the body and the genital sucker, which is smaller, lies close behind and a little to one side of the ventral sucker. It has an average diameter of 150 μ, and bears a circlet of seventy-five to eighty rods which are about 20 μ in length and have five pointed processes in a row along their convex surface. This circlet of rods is broken for a short distance on the side of the genital sucker toward the ventral sucker. The eggs are light brown, operculate, thick-shelled and contain a fully developed, ciliated, embryo when oviposited. The egg may have a knob resembling that on a *Clonorchis* ovum but is less prominent. The average size is from 20 μ to 30 μ by 15 μ to 17 μ.

4. POSITION OF THE HOST

Heterophyes heterophyes inhabits the middle third of the small intestine and often occurs in very large numbers. It is usually free within the lumen of the intestine but has been found between the villi and sometimes attached to the mucous membrane near the bases of the villi. *Heterophyes heterophyes,* in most cases, appears to be harmless to the host, although abdominal discomfort, nausea and tenderness below the right costal margin are said to have disappeared after the expulsion of a number of these flukes.

5. LIFE-CYCLE

Nothing is known of the free life of the miracidium of *Heterophyes heterophyes* or of the mollusc which serves as the first intermediate host. Onji and Nishio (1915) found encysted cercariæ in the muscles and on the peritoneum of fresh-water fish (*Mugil japonicus*) and noted that these fishes were eaten raw in endemic centers. By feeding infected fish to experimental animals, these authors were able to follow the details of development from the metacercariæ to the adult. Kobayashi (1923) discovered encysted distome larvæ in specimens of mullet (*Mugil cephalus*) in Port Said which later proved to be metacercariæ of *Heterophyes* and believed to be closely allied to *H. heterophyes*. Through feeding experiments, Khalil in Egypt has proven Kobayashi's assumptions, having shown that these cysts contain the metacercariæ of *H. heterophyes*.

III. *Heterophyes katsuradai* (Ozaki and Asada, 1926)

Ozaki and Asada in 1926 obtained this species of *Heterophyes* by anthelmintic means from a man suffering from diarrhea in the Settsu Hospital in Kobe, Japan. This species differs from the other known species of this genus in the relative size of the acetabulum to the body length, the shortness of the neck and the distribution of the vitellaria. The acetabulum is remarkably larger than in other species compared to the size of the body, having a diameter greater than a fourth of the body length. The vitellaria are fairly well developed, extending laterally to the central level of the testes; on the dorsal side they cross the median line and unite at the anterior border of the testes. The eggs are thick shelled, operculate, yellowish brown and 25.3 μ to 25.9 μ by 14.3 μ to 15 μ. The miracidium is developed while the eggs are in the uterus.

The life-cycle of *H. katsuradi* is not known but it is probable that man becomes infected by eating raw or insufficiently cooked fish containing the encysted cercaria.

IV. *Metagonimus yokogawai* (Katsurada, 1912)

1. HISTORICAL

Yokogawa discovered in 1911 larval trematodes encysted in the gills, under the scales and in the muscles of certain fresh-water fish. He carried out feeding experiments and succeeded in getting these cysts to develop in puppies. After learning the character of the eggs of the adult produced experimentally, he recognized that the eggs of the same species were found in human feces in Formosa and which had been taken for those of the liver fluke, *Clonorchis sinensis*. Katsurada described the fluke in 1912 and suggested that this parasite was probably widely distributed in Japan, since he had found its eggs in seven out of nine fecal examinations made of his assistants. It was soon discovered that this species occurs frequently in Japan and is more prevalent and widely distributed in that country than the liver fluke, *Clonorchis sinensis*. *M. yokogawai* is now known to occur in Japan, Korea and China.

2. DESCRIPTION

Metagonimus yokogawai (Figure 89) is a small fluke of about the same size as *Heterophyes heterophyes*. The uterus occupies the

middle of the body and the two testes are arranged posteriorly. The common genital pore lies to the side of the acetabulum and is not surrounded by a collar of spines. The body is covered with minute spines which are particularly prominent about the oral sucker. The eggs are operculate and although resembling those of *Clonorchis sinensis,* the operculum is not set into a groove of the shell as in the latter species. The eggs measure 28 μ in length by 16 μ in breadth and are said to have a knob at the pole opposite the operculum.

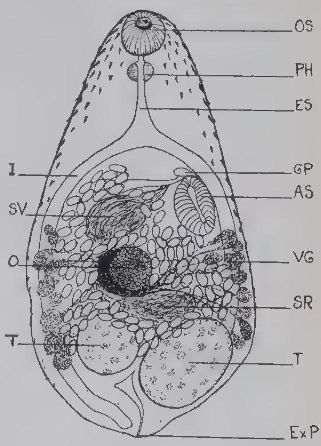


FIG. 89.—*Metagonimus yokogawai.* OS, oral sucker; PH, pharynx; ES, esophagus; GP, genital pore; AS, ventral sucker; VG, vitellaria; SR, seminal receptacle; T, testis; O, ovary; SV, seminal vesicle; O, ovary. (Partly after Yokogawa)

3. POSITION OF THE HOST

Metagonimus yokogawai is usually found in the small intestine of man and dog, especially in the upper and middle part of the jejunum and rarely in the duodenum and ileum. Exceptionally, it has been reported from the cæcum. The adult worms are found in the mucus on the surface of the mucous membrane, while the younger stages are found deeply imbedded in the mucosa or submucosa. The length of life of this parasite is not definitely known, but probably is about two years.

4. LIFE-CYCLE

The life-cycle of *M. yokogawai* is not completely known. The cercariæ develop in the snail, *Melania libertina,* and upon their escape from that host penetrate and become encysted in the trout, *Plecoglossus altivelis.* This fish is often eaten raw or after immersing in soy sauce or vinegar. The cysts are found most frequently in the subcutaneous tissues about the scales, gills, fins and tail and rarely in the musculature. Those found under the scales are usually round, measuring about 0.13 mm. in diameter, while those in the gills are ellipsoidal in shape having a length of about 0.15 mm. and a breadth of 0.1 mm.

V. *Heterophyidæ of Lower Mammals*

Tanabe in 1922 described *Stamnosoma armatum* from the small intestine of birds (the night heron) and mammals in Japan. Nishigori (1924) published an extended account of the life-cycle of a second species of that genus, *S. formosanum,* also from birds and mammals in Formosa, but morphologically distinct from *S. armatum.* The probable natural hosts of these two flukes is the night heron, *Nycticorax nycticorax.* Both species were found to be experimentally infective to mammals, including man.

The second intermediate host of *S. armatum* is a cyprinoid fish. The host of the asexual stages is not known. The asexual generations of *S. formosanum* develop in a number of species of snails of the genus Melania and the cercariæ have been found to encyst in several species of fresh-water fish, including *Carassius auratus, Channa formosana, Cyprinus carpis, Gambusia affinis, Pseudorasbora parva,* and *Rhodeus ocellatus.*

Two species in the genus *Monorchotrema* have been described by Nishigori (1924) which are designated as *M. taihokui* and *M. taichui,* the specific names referring to the localities in which the parasites were first found. These flukes are closely related to *Stamnosoma, Heterophyes* and *Metagonimus,* but differ from these genera mainly in that they have but a single, large testis instead of the pair of testes described for the group. *M. taihokui* and *M. taichui* bear a close resemblance to each other, and as their life-cycle, free-swimming miracidial and cercarial stages, and the manner of development in the primary host are also similar, they probably are one and the same species, *M. taihokui.* An extensive study of the life-cycles of these flukes was made in 1926 by Faust and Nishigori.

Monorchotrema taihokui occupies the middle and lower parts of the jejunum of its host where it deeply invades the mucous membrane and becomes attached. It has been reported as a natural parasite in the night heron, *Nycticorax nycticorax,* and in the dog and cat, and in experimental infections in various mammals, including man, of Northern and Central Formosa.

The egg of *Monorchotrema* has a comparatively thick shell with distinct thickened shoulders where the operculum joins the shell, and contains the completely formed miracidium. The ova of *M. taihokui* vary from 24.5 μ to 29 μ in length by 12.2 μ to 15.3 μ in breadth. Those of *M. taichui* are slightly smaller ranging from 20.7 μ to 23 μ in length by 9.2 μ to 10.7 μ in breadth, and are lighter in color than

those of *M. taihokui*. These ova may be easily mistaken for those of *Clonorchis sinensis* or *Metagonimus yokogawai*.

Species of *Melania*, *M. reiniana* var. *hidachiens* and *M. obliquegranosa*, serve as the first intermediate host for *Monorchotrema*. Rediæ are produced within the sporocysts, and, after a period of five to six weeks, mature cercariæ develop within the rediæ. The cercariæ escape from the snail and encyst on the cartilaginous tissues of the fins and head and on the gills of various fresh-water fishes. Infection in the primary host is incurred by eating raw infected fish.

VI. *Echinostoma ilocanum* (Garrison, 1908)

This species is of the family ECHINOSTOMATIDÆ (Looss 1902) Poche, 1926. In the trematodes belonging to this family there is a reniform collar surrounding the oral sucker which is open on the ventral surface and bears a series of strong spines. They are, for the most part, parasitic in birds and mammals, with two species in man. Other representative genera of the family are *Euparyphium*, *Artyfechinostomum* and *Echinochasmus*.

1. HISTORICAL AND GEOGRAPHIC DISTRIBUTION

Echinostoma ilocanum (Figure 90) was first described by Garrison in 1908 under the name *Fascioletta ilocana* from twenty-one specimens obtained after a vermifuge treatment to a native prisoner in Manila, Philippine Islands. Later Garrison reported four other cases which were diagnosed from fecal examinations. All five cases came from the Northwestern provinces of the Island of Luzon. Odhner, in 1911, studied the morphology of this parasite in detail from specimens sent him by Garrison, and placed it in the genus *Echinostoma* Rud. This infection was again reported in 1918 by Hilaria and Wharton from five natives from the province of Zambales, Luzon, and it is believed by these authors that this fluke is probably a common parasite of the natives in Zambales and other parts of Luzon. *Echinostoma ilocanum* lives in the intestine, but it is not known what part of the intestine, since all the specimens were obtained after vermicidal treatment.

2. MORPHOLOGY

Echinostomum ilocanum is a small, oblong trematode ranging from 4 mm. to 6 mm. in length and from 0.75 mm. to 1.35 mm. in

breadth. The anterior part of the body may be well covered with scale-like spines, but as these are very unstable and the least handling causes them to be lost, they may occur only in irregular patches along the margin of the body. As many as forty-nine spines have been counted in the collar. The oral sucker is small, having a diameter of about 0.18 mm. The acetabulum is between two to three times as large and is situated about 0.7 mm. from the anterior end of the body. The eggs are operculate, oval, and vary from 92 μ to 114 μ in length and from 53 μ to 82 μ in breadth. They are undeveloped when they leave the host, a characteristic typical for the echinostomes.

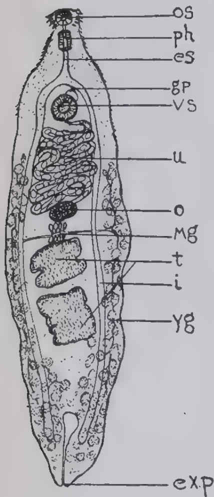


FIG. 90.—*Echinostomum ilocanum*. *os.*, oral sucker; *ph.*, pharynx; *es.*, esophagus; *gp.*, genital pore; *VS*, ventral sucker; *u.*, uterus; *o.*, ovary; *mg.*, Mehlis' gland; *t.*, testes; *i.*, intestine; *yg.*, vitellaria; *exp.*, excretory pore. Magnified. (Redrawn from various authors)

3. LIFE-CYCLE

Nothing is known of the life-cycle of *Echinostoma ilocanum* beyond the fact that the miracidium hatches in about ten days after the ova are placed in water. A discussion of life histories of related forms will be taken up later.

VII. *Euparyphium malayanum* (Leiper, 1911)

1. HISTORICAL AND GEOGRAPHIC DISTRIBUTION

Leiper in 1911 described this parasite as *Echinostoma malayanum* from material obtained at autopsy from the small intestine of a Tamil residing in the Malay States. Odhner reviewed this species in 1913 and placed it in the genus *Euparyphium*. It has also been reported from Siam. It is probable that this species is only an incidental parasite of man.

2. MORPHOLOGY

Euparyphium malayanum is tongue-shaped, varying in length from 8 mm. to 12 mm. and in breadth from 3 mm. to 3.3 mm. and has a thickness of about 1 mm. The musculature of the ventral surface is very strongly developed which causes preserved specimens to be somewhat rolled up with the dorsal surface out. The collar is distinctly set off from the rest of the body, has a diameter of 0.6 mm.

and is set with forty-three spines. The length of these spines varies from 43 μ to 51 μ and occasionally up to 57 μ, and their thickness at their bases is from 14 μ to 15 μ. Strong, scale-like spines are present; they extend over the whole ventral surface but are limited on the dorsal surface to the region in front of the pharynx.

The life-cycle is not known.

VIII. *Euparyphium jassyense* (Leon and Cuirea, 1922)

This parasite was obtained from a Persian forty-five years old after anthelmintic treatment. The worm is elongate, oval, reddish in color and measures from 5.44 mm. to 7.60 mm. in length and from 1.05 mm. to 1.38 mm. in breadth. The cuticula is set with rectangular spines 22 μ x 15 μ along the lateral borders of the body and extend almost to the posterior extremity.

Nothing is known of the life-cycle of *Euparyphium jassyense.*

IX. *Artyfechinostomum sufrartyfex* (Lane, 1915)

This species of trematode was described by Lane in 1915 from material obtained after anthelmintic treatment from a child eight years old who had lived all her life on a tea estate in Assam. Lane's description of *A. sufrartyfex* closely agrees with that of *Euparyphium malayanum.* The specific distinctness is based almost entirely on the extent of the cirrus sac behind the acetabulum. It is probable that these two forms belong to the same species.

X. *Echinochasmus perfoliatus japonicus* (Tanabe, 1919)

Tanabe in 1915 obtained adult echinostomes by feeding to cats and dogs encysted cercariæ which he found in the gills of several different species of fresh-water fish. This fluke closely resembles *Echinochasmus perfoliatus* Ratz, and was given the name *E. perfoliatus* var. *japonicus.* In 1919 Tanabe proved that this fluke can infect man by experiments on himself in which he obtained adults from cysts ingested with fish. It is probable that this fluke is a common parasite of domestic animals, the dog and cat, and that its occurrence in man is only incidental.

The encysted cercariæ live in the gills of about twenty different species of fresh-water fish and when ingested by the final host, dog or cat, they become mature adults in from eight days to a month. The molluscan host is *Bythinia striatula japonica* which serves

also as the intermediate host of the liver fluke of man, *Clonorchis sinensis.*

XI. *Life-Cycle of Echinostomes*

Many different species of adult echinostomes have been described but our knowledge of the complete life-cycle of these trematodes is complete for only one species, *Echinostomum revolutum,* a common parasite of ducks and geese. The life-cycle of this species was followed in detail by Johnson (1920) in California. Johnson found that the miracidium of this fluke escapes from the egg in about three weeks under favorable conditions, and, after penetrating the snail host, *Physa occidentalis,* it develops directly into a mother redia which produces a generation of rediæ in which cercariæ develop. These cercariæ either encyst without escaping from the snail or after their escape from the snail, may reënter the same specimen or another species to form the cyst. The infection is carried to the primary host, when the infected snail is eaten by ducks and geese.

It is probable that other echinostomes follow somewhat similar steps in their development and that infection in the primary host is the result of ingesting the encysted cercariæ with the food of that host.

XII. *Gastrodiscoides hominis* (Lewis and McConnell, 1876)

Gastrodiscoides hominis is an amphistome and differs widely in morphology from the distome species just discussed. It belongs to the family GASTRODISCIDÆ Stiles and Goldberger, 1910, which, in addition to the general characters of the AMPHISTOMATA, is distinguished by a discoidal body divided into cephalic and caudal portions.

I. HISTORICAL

Gastrodiscoides hominis was first described by Lewis and McConnell as *Amphistomum hominis* in 1876 from material sent them by O'Brien and Curren which had been obtained during an autopsy on an Assamese who had died of cholera. It was later placed in the genus *Gastrodiscus.* Giles also reported in 1890 that he frequently encountered this fluke during an investigation of kala azar and beriberi in India. Leuckart reviewed the morphology of this species in 1886-1891 and later Stephens (1906) made further studies on its structure.

Brau and Bruyant reported the infection from an Annamite in Cochin China which is the first known infection with this parasite outside of India. Leiper (1913) reviewed the morphology of this fluke from material obtained from British Guiana and placed it in a new genus, *Gastrodiscoides.*

2. DISTRIBUTION AND FREQUENCY

Gastrodiscoides hominis has been reported from the Malay States, Assam, India, Cochin China and British Guiana (Indian immigrants). According to Chandler (1928) this species is common in pigs and occurs sporadically in man of eastern India. It is probably a normal parasite of the domestic pig and its presence in man but accidental. It has also been reported in deer from the Malay States and in monkeys.

3. DESCRIPTION

Gastrodiscoides hominis (Figure 91) when alive is reddish. The body is very contractile and when fully extended measures about 1 cm. in length. Preserved, sexually mature adults vary from 5 mm. to 7 mm. in length and from 3 mm. to 5 mm. in greatest breadth, tapering to about 2.5 mm. anteriorly. The body is divided into two distinct regions, (1) the anterior cone and (2) the enlarged, posterior disc which bears the acetabulum on its posterior median margin. The cuticula over the surface of the ventral disc is smooth, no spines are present. The eggs are operculate and have a length of about 150 μ and a width of 72 μ.

FIG. 91.—*Gastrodiscoides hominis.* Slightly magnified. (From Fantham, Stephens, and Theobald, *Animal Parasites of Man.* After Leuckart)

4. POSITION IN THE HOST

The adult of *Gastrodiscoides hominis* is found in the cecum and large intestine of the host. Very little is known of its pathogenicity.

5. LIFE-CYCLE

The larval stages and intermediate hosts of this species are not known. A general discussion of the life histories of the amphistomes will be given later.

XIII. *Watsonius watsoni* (Conyngham, 1904)

Watsonius watsoni is also an amphistome but of the family PARAMPHISTOMIDÆ Fishoeder, 1901. The body of these amphistomes is not discoidal nor divided into cephalic and caudal portions.

I. HISTORICAL

Conyngham in 1904 described *Watsonius watsoni* from material obtained at autopsy from the jejunum and duodenum of a negro who had come from the late German West Africa to Northern Nigeria. The negro had died from inanition and diarrhea. Shipley (1905), Stiles and Goldberger (1910) and Leiper (1913) have contributed much to our knowledge of the morphology of this parasite. Railliet, Henry and Joyeux in 1912 discovered this species in the cecum of a monkey, *Cercopithecus callitrichus,* which suggests that this fluke is only an incidental parasite of man.

2. DESCRIPTION

Watsonius watsoni (Figure 92) is reddish yellow in color when living. It is oval to pyriform in shape and has a length of 8 mm. to 10 mm. and a breadth of 4 mm. to 5 mm. The acetabulum is large, subterminal and with the margin projecting. The eggs are oval, operculated and have a length of 122 μ to 130 μ and a breadth of 75 μ to 80 μ. Nothing is known of its life history.

FIG. 92.—*Watsonius watsoni.* 4/1. (From Fantham, Stephens, and Theobald, *Animal Parasites of Man.* After Shipley)

XIV. *Amphistomes of Lower Vertebrates*

The amphistomes are frequently found in lower vertebrates. Among the commoner North American species are *Diplodiscus temperatus* from the rectum of frogs; *Allassostoma magnum* from the intestine of turtles, *Pseudemys; Zygocotyle ceratosa* from the intestine of the duck, *Anas platyrhynchos;* and *Amphistomum cervi* from the rumen of domestic and wild ruminants, all of which may be obtained without difficulty for laboratory studies.

XV. *Amphistome Life-Cycles*

Although nothing is known of the life histories of the amphistomes found in man, it is possible to infer what stages occur from life-cycles of amphistomes from lower animals which have been followed in detail. Looss, in 1892, studied the life history of *Diplodiscus subclavatus* which lives in the adult stage in the rectum of the frog. The eggs of this fluke are entirely undeveloped when they are expelled from the host and the development of the miracidium, therefore, takes place in the open. The miracidium, after escaping from the shell, penetrates into a species of fresh-water snail where it metamorphoses into the mother sporocyst, which in turn produces a number of rediæ. Inside of the rediæ develop the cercariæ which, after escaping from the snail host, encyst in the open. These encysted cercariæ (metacercariæ) are ingested by the final host (frog) and grow into adults in the rectum. The cercariæ of the amphistomes have certain well-defined structural similarities. The sucker and digestive system are like those of the adult. They have well-defined eye-spots and well-developed cystogenous glands. They also are of large size, develop within rediæ and have the parts of the reproductive system clearly outlined.

Judging from the character of the life-cycle of *Diplodiscus subclavatus* and from the life-cycles of other amphistomes from other hosts which have been found similar to that of *D. subclavatus* it is probable that the amphistomes found in man follow the same general lines of development, and that man becomes infected with these parasites by ingesting the encysted stages, either with uncooked food or in water.

XVI. *Diseases Due to Intestinal Trematodes*

I. SYMPTOMS

Intestinal trematodes, especially when occurring in large numbers are known to cause abdominal discomfort, nausea, tenderness below the right costal margin, diarrhea, anemia, and edema. Large numbers, however, are not always necessary to give rise to noticeable symptoms, for many patients harboring but one or two worms (e.g. *Fasciolopsis buski*) often show appreciable disease. In man, by far the most important of the intestinal flukes is *Fasciolopsis buski.*

Goddard (1919) recognizes three stages in fasciolopsiasis: (a)

A period of latency in which there may be no marked symptoms but probably some asthenia and mild anemia. Barlow refers to this period as one of growth or development extending from the infection to a size sufficient to produce an amount of toxin which would cause apparent injury, and looks upon the onset of the clinical manifestations as occurring in a gradually increasing scale of severity, due to the growth of the parasites which develop to maturity without intermission. (b) A period of several months of diarrhea with abdominal pain. There is no jaundice and no blood in the stool. Diarrhea, according to Barlow, is not a constant symptom and may alternate with periods of constipation. (c) A period of edema in which the anemia is increased and the edema becomes more distressing. The edema may appear within twenty days of infection in case the patient is small or undernourished and the infection is massive. In fatal cases there is a marked edema with ascites and an extensive anasarca. Death, when it occurs, is apparently due to exhaustion. According to Barlow (1925) the apparent anemia is largely due to viewing the blood stream through an overlying edema. The edema does not involve the lungs and probably not the chest cavity even in advanced cases. Advanced cases show a definite demarcation of the chest which is exceptionally free from any edema.

2. TREATMENT

Chloroform, thymol, eucalyptus oil, beta naphthol and carbon tetrachloride have been used with success in expelling intestinal flukes. Barlow finds carbon tetrachloride the most efficacious anthelmintic in the treatment of fasciolopsiasis. These drugs are administered in the same manner as in ancylostomiasis. After the expulsion of the flukes the symptoms rapidly disappear.

CHAPTER XIX

THE LIVER FLUKES

The majority of trematodes which inhabit the gall ducts of man belong to the family OPISTHORCHIDÆ Lühe, 1901. The members of this family are very transparent, small to medium in size with the body tapering anteriorly. The oral and ventral suckers are close together and are very weakly developed. The testes are near the posterior end, one behind the other, and are either lobed or branched, but not dentritic. They are parasites in the bile ducts of mammals and birds. The second intermediate host is a fresh-water fish. Other liver flukes which will be considered here belong to FASCIOLIDÆ Railliet, 1895, and DICROCŒLIIDÆ Odhner, 1910.

I. *Clonorchis sinensis* (Cobbold, 1875)

1. HISTORICAL

Clonorchis sinensis Cobbold was described by McConnell in 1875 from material obtained at autopsy of a Chinese carpenter living in Calcutta. The liver on this post-mortem examination was found to be much enlarged and tense with much distention of the bile ducts. On sectioning the liver, small worms escaped with the bile fluid and were believed by McConnell to be the cause of the pathological condition of the liver. Cobbold (1875) recognized that the fluke described by McConnell was a new species and gave it the name *Distoma sinense*. In 1877 MacGregor (1878) found the same trematode in several Chinese at Port Louis, Mauritius, and erroneously attributed a form of paralytic disease to its presence. In 1878 McConnell reported another case in a Chinese cook in Calcutta and suggested the possibility that the infection came from eating insufficiently cooked fish. It was also noted that all cases had been Chinese. In 1883 Kiyono, Nakahama, Yamagata and Suga published an account of the liver fluke in Japan. Baelz also published on the liver fluke in Japan in 1883, stating that these parasites were quite frequent in Japan, and recognized two species, separated principally on size differences. The smaller one was regarded as of pathological

significance and which he named *Distoma hepatis endemicum perniciosum,* while the larger type was thought harmless and was designated as *Distoma hepatis innocuum.* As Baelz had confused the clinical picture of the disease produced by this worm with that of *Schistosoma japonicum,* he later changed his views and came to look upon the two species as one and the same. Blanchard in 1895 created the genus *Opisthorchis* in which he placed the species *Distoma sinensis* Cobbold. It remained in that genus until 1907 when Looss established the genus *Clonorchis* for the Oriental liver fluke.

Looss concluded that there are two distinct species. The larger, which is the type found in China, was called *Clonorchis sinensis* Cobbold, and was believed to be harmless, and the smaller species, named *C. endemicus,* found mostly in Japan and in French Indo-China, was believed to be pathogenic. Verdun and Bruyant (1908) also made an extensive study of the species question in *Clonorchis* and concluded that while there were two distinct types, the differences were not sufficient to class them as distinct species and therefore established two varieties *Clonorchis sinensis major* and *Clonorchis sinensis minor.* Kobayashi (1917) by experimental methods and Ch'en Pang (1923) employing morphological comparisons proved that the differences found by earlier writers were individual variations and that there is only one species which should be referred to as *Clonorchis sinensis* Cobbold.

Saito (1898) was the first to study the viable ova and living miracidia, and Kobayashi (1911-1917) discovered the second intermediate host (various species of fresh-water fish) and was able to produce experimentally the adults from the encysted cercariæ found in the fish. Muto in 1918 found the cercaria of *C. sinensis* in a fresh-water snail, *Parafossarulus striatulus* var. *japonicus.* Faust and Khaw (1927) made an extensive study on the biology and epidemiology of *Clonorchis* infection in China which greatly adds to our knowledge on the life-cycle of this parasite.

2. DISTRIBUTION AND FREQUENCY

Clonorchis sinensis is a characteristic parasite of man and is frequently found in fish-eating mammals of the Orient including the countries adjacent to the China and Yellow Seas, namely Japan, Korea, China, Formosa and French Indo-China. The infection appears to be limited to the distribution of the snail host, *Parafossarulus striatulus* and its close relatives. In man it has been reported frequently from countries outside of the Orient, including

the United States, but in all such cases the infection has been among Chinese or Japanese who originally came from endemic districts of China or Japan. There are no authentic records of the spread of this parasite into new regions by immigration. In Japan the liver fluke is clinically important only in the Okayama district, although it is more or less distributed throughout the mainland as well as in Shikoku and Kyushu. In Korea the infection is common only in the southern part of the peninsula. In China the most important infection with *Clonorchis* in man is in the Kwantung Province, Southeastern China, where the greater part of the infection is acquired through the eating of infected, raw, fresh-water fish. Occasionally native infections of *Clonorchis* in man are encountered in Central China but in North China the native population is free from this parasite. In French Indo-China the most heavily infected area, and probably of the entire endemic region, is found in the delta of the Red River. The persons most commonly infected are the native boatmen and soldiers. In children the infection usually is slight, but increases from fifteen years to old age, being highest after fifty years of age.

The number of individuals of *Clonorchis* in an infected host may be very great. Twenty-one thousand worms were obtained by Sambuc and Beaujean (1913) from a human case in Indo-China. Persons harboring more than 1,000 worms are not uncommon, but the average runs usually less than 100. Among the lower animals with natural infections, the number of clonorchids may also be very high. Faust has found 2,500 worms in a dog which had acquired a natural infection in Peking. The general average in such animals is, however, usually less than 100 worms.

The incidence of *Clonorchis* in the lower animals of China does not parallel its incidence in man. Cats and dogs of South China are lightly infected while in Central China these animals are very heavily parasitized. In North China they are moderately heavily infected as far as Peking but north and west of Peking the infection is very rare. The following list of lower mammals have been found naturally infected with *Clonorchis:*

Dog—Japan, Korea, North, Central and South China, Formosa.
Cat—Japan, Korea, North, Central and South China, Formosa.
Wild cat—North China.
Hog—Japan.
Marten—North China.
Badger—North China.
Siberian mink—Korea.

Guinea pig—North China. This animal had been used in experimental tuberculosis.

Most laboratory animals except birds have been found to be susceptible to infections with *Clonorchis.*

3. POSITION IN THE FINAL HOST

Clonorchis sinensis normally inhabits the bile passages of its host. It migrates to the more distal portions of the bile tracts when still immature and there grows to maturity. Apparently there is but little or no migration from this position during its adult life or that of the host. The worms are usually found free in the cavity of the ducts, or crowded into the small bile capillaries, where they are bathed in the bile fluid. They have also been obtained from the gall bladder at autopsies of experimental animals under anesthesia. One lobe of the host's liver may sometimes be heavily infected (the left lobe) while the remainder of the organ will be relatively free from the infection. Post-mortem shows the common duct frequently blocked with worms which may also be found in the duodenum and the pancreatic duct, especially in heavy infections. It can not, however, remain alive for any length of time in the alimentary tract since it is rapidly digested by the intestinal fluids.

The food of the adult flukes is believed to be the secretion from the mucosa of the bile ducts.

4. LONGEVITY OF ADULT IN THE BILE PASSAGES

No direct observations have been made on the longevity of the adult worm within the bile passages. Watson (1918) records an infection in a Chinese in Panama which was believed to exist for twenty years without reinfection, and Moore (1921) reports other cases with infections believed to be of from five to twenty years duration. Faust and Khaw (1927) have observed the infection in Chinese University students from Southern endemic centers who had lived continuously for several years in Peking where raw fish is not eaten by man. Several of them had remained infected for a period of five years of abstinence. It seems probable, therefore, that after an infection with *Clonorchis sinensis* is once established, it may last from five to twenty years or more.

5. MORPHOLOGY OF THE ADULT FLUKE

Clonorchis sinensis (Figures 93 and 94) when alive are opalescent gray in color, but if allowed to die *in situ* preceding autopsy

they become discolored through the absorption of the bile pigment and take on a deep brown color. They are mostly transparent and are very flabby, due to the weakly developed musculature. The body has a more or less rounded, tapering posterior end. The anterior end is more acute, terminating bluntly with the anterior sucker.

FIG. 93.—*Clonorchis sinensis*. Showing the essential features for specific diagnosis of the adult worm (x 8). (After Faust)

Marked differences have been recorded in sizes of *Clonorchis sinensis* which led Looss and others to believe this to be an important criterion of species in this genus. That size is not a species characteristic has been shown by a number of authors on this subject. Faust and Khaw (1927) have observed that (1) a few clonorchids in the bile passages of a large animal (man) have plenty of room to attain their full growth, and that the flukes obtained at autopsies of human cases are usually large; (2) that if a large number of these flukes live in the bile ducts of the same host, they crowd one another so that they do not usually attain such a size; and (3) large numbers of such flukes in the bile passages of small animals were usually small in size. In one experimental infection (cat) these authors obtained at autopsy eleven mature worms, one of which measured nearly twice the length of the other ten. The ten smaller ones were obtained from the distal bile capillaries of the left lobe, while the large worm was recovered from the proximal bile passage. The following table gives Faust and Khaw's measurements of over one hundred specimens of *C. sinensis* obtained from three human autopsies.

AVERAGE SIZE MEASUREMENTS OF CLONORCHIS FROM HUMAN AUTOPSIES

Case No.	*Source*	*Worms Obtained*	*Worms Measured*	*Length in mm.*	*Breadth in mm.*
1	Korea	93	93	12.1-20.1	3.4-4.6
2	South China	100	50	11.5-18.0	3.6-4.0
3	Hongkong	505	25	13.0-16.1	2.8-3.5

The egg of *Clonorchis sinensis* is a yellowish-brown color, oval in shape, resembling an old-fashioned carbon-filament, electric light

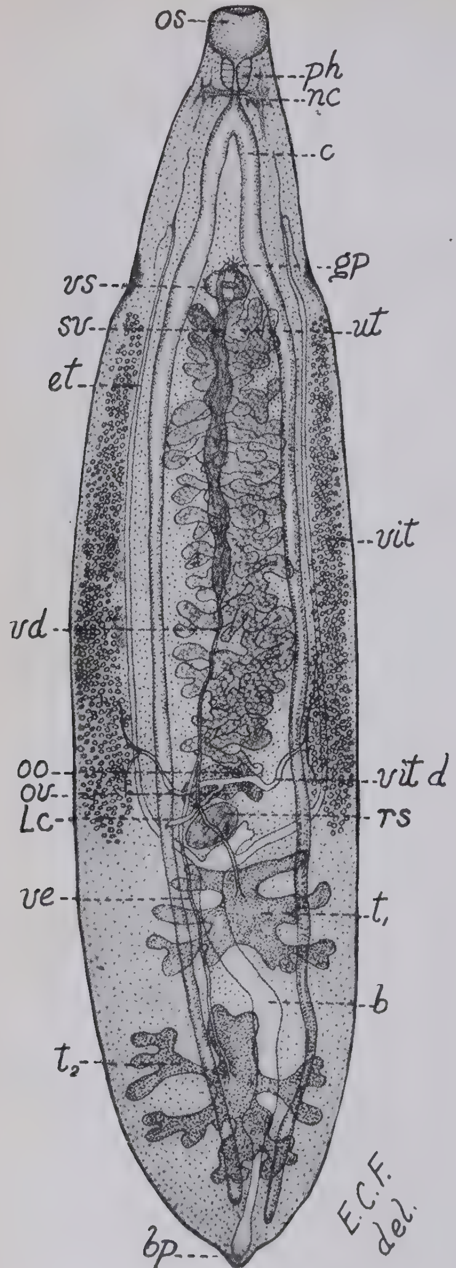


FIG. 94.—*Clonorchis sinensis.* Showing detailed internal structure of the adult worm. *os.*, oral sucker; *ph.*, pharynx; *nc.*, nerve center; *c.*, intestinal crura; *gp.*, genital pore; *ut.*, uterus; *vit.*, vitellaria; *vit.d.*, vitelline duct; *rs.*, seminal receptacle; *t.*, testis; *b.*, bladder; *vs.*, acetabulum; *sv.*, seminal vesicle; *vd.*, vas efferens; *t2*, testis; *bp.*, excretory bladder pore. (After Faust)

bulb, and has a size average of 29 μ in length and 11 μ in breadth. The embryo is fully developed and viable at the time the ova are expelled from the host. The operculum is located at the narrower pole and is vaulted, and so inserted within the rim of the shell that its contour does not follow that of the rest of the shell. The shoulders at the opercular rim are prominent and form a characteristic for the diagnosis of *Clonorchis*. The shell is uniformly thick throughout and shows etchings of an arabesque, polygonal design (Figure 95). These etchings are best seen when the eggs are viewed in a weak solution of toluidine blue or potassium permanganate. A hooklike appendage or protuberance is situated in normal ova in the middle of the ab-opercular which is of a lighter color than the rest of the shell.

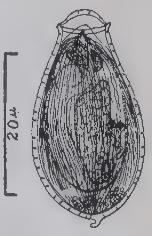


FIG. 95.—Egg of *Clonorchis sinensis*. (After Faust)

6. LIFE-CYCLE

The ova of *Clonorchis* are deposited by the adult worms in the biliary passages of the host and from there they pass to the intestinal tract, after being stored up in the gall bladder. To the present day the exact method by which the snail host becomes infected with *Clonorchis* is not definitely known. Experimental evidence, however, indicates that the miracidia do not hatch in the open and actively penetrate the snail host, as in the case of other flukes we have mentioned, but that the unhatched ova are taken passively with food into the snail's digestive tract, and after hatching, the miracidia penetrate through the intestine into the vascular spaces and become the sporocyst. Here the sporocyst becomes an elongated structure, which contains a number of young rediæ, in each of which the pharynx and the anlage of the cecum are present. These rediæ break out of the thin-walled sporocyst and escape into the vascular sinuses. These rediæ are characterized by having one or more transverse constrictions along the body, due to muscular contractions, and the absence of the lateral "feet" and birth pore in the region of the neck which is typical of many rediæ. From six to eight cercariæ develop within each redia which, upon maturity, break out of the mother rediæ into the free inter-hepatic lymph spaces of the host and finally emerge from the snail into the water to seek their piscine host.

The sporocyst and rediæ of *Clonorchis sinensis* are found most commonly in various species of snails of the subfamily BITHYNIINÆ,

the snails, *Parafossarulus striatulus,* and *Parafossarulus striatulus* var. *japonicus,* and *Bithynia fuchsiana* are the more important hosts of this infection.

The mature, free-swimming cercaria of *Clonorchis sinensis* is of the lophocercous type. When relaxed, the body measures from 250 μ to 275 μ in length by 60 μ to 90 μ in breadth. The tail is long, 650 μ to 750 μ, with a more or less truncated tip (Figure 96). On either side of the tail, the integument is drawn out into transparent alæ which run parallel to the tail margins. Six pairs of unicellular, cephalic glands occupy the center of the body. The ducts of these glands pass forward and end in hollow, attenuated boring spines on either side of the oral aperture. These glands secrete a substance which is histolytic and aids the cercaria in its invasion into the flesh of fresh-water fish, the second intermediate host. The cercariæ attach themselves to the body of the fish, and, after a partial penetration into the tissues, encyst in this host, which may later become food of the final host. The encystment may take place in the musculature of the fish or on the underside of the scales or on the skin. Encystment usually occurs only after the cercaria has used up its histolytic secretions in its endeavor to gain a foothold in the tissues of the fish. The tail is cast off and the true cyst capsule is formed rapidly from the cystogenous granules which apparently absorb large quantities of water. The cystogenous fluid is exuded from the tissues of the larva and quickly forms into a comparatively thin, hyaline capsule. The cercariæ which encyst within the muscles of the fish possess an additional outer fibrous covering which is formed by the reaction of the host tissues, and which is probably provoked by toxic byproducts of the parasite. The mature cyst is elliptical in outline, measuring in the largest specimens 135 μ to 145 μ by 90 μ to

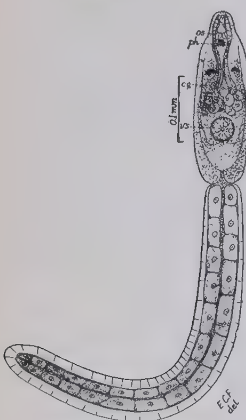


FIG. 96.—Cercaria of *Clonorchis sinensis; os.,* oral sucker; *cg.,* cephalic secretory gland; *vs.,* acetabulum. (After Faust)

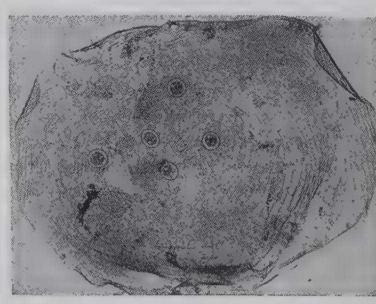


FIG 97.—Encysted metacercaria on the under side of fish scale of *Hemiculter kneri,* a second intermediate host. Magnified. (Photograph from Faust)

100 μ. The long axis of the cyst when it is embedded in the muscle lies parallel to the muscle fibers. When the cysts are located under the scales of the fish they are somewhat compressed and discoidal in shape (Figures 97 and 98).

Thirty-four species of fresh-water fishes are known to harbor the cysts of *Clonorchis sinensis.* Of these *Pseudorasbora parva* is most commonly involved. It has a wide distribution and is often eaten raw, in vinegar or in soy sauce. Other hosts, *Ctenopharyn-godon idellus, Hypothalmichthys nobilis* and *Labeo jordani* are especially prized for food in South China.

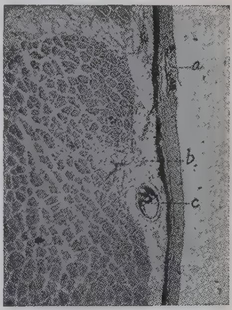


FIG. 98.—Section through superficial layers of *Culter brevicauda,* showing (a) the point of entrance of the cercaria into the subintegumentary layer; (b) strands of connective tissue with small round-cell accumulations in the region through which the larva has passed, and (c) the metacercaria recently encysted. (Photograph from Faust and Khaw)

The encysted cercariæ can withstand high temperature. Kobayashi (1917) found that they were killed if the flesh containing the cysts was roasted or boiled for fifteen minutes or kept in water at 100° C. for fifteen minutes. Faust and Khaw (1927) found that infected fish heated at 80 ° C. for one hour still harbored viable cysts. These observations show that infections can even arise from eating apparently "well-cooked" fish.

7. METHODS OF ENTRANCE INTO FINAL HOST

Three ways by which man may become infected with *Clonorchis* have been described by various writers: (1) by ingesting water containing living cysts which have been discharged or fallen from fish, (2) by handling the fish in the catching and preparation as food during which the cysts are transferred to the mouth and swallowed and (3) by eating raw or imperfectly cooked fish containing the *Clonorchis* cysts. While the first two methods are possible, it is probable that they occur but seldom under natural conditions. It is evident that the chief source of infection is by the direct ingestion of fish containing the cysts when served raw or only partially cooked.

8. DEVELOPMENT IN THE FINAL HOST

Upon ingestion of the cysts by the final host, the fibrous outer cyst wall, if present, is first digested away by the gastric juice and

the encysted larva passes into the duodenum where the true cyst wall is ruptured, largely by the activity of the larva within, and the free form travels into the bile ducts where it grows to maturity. By the sixteenth day after ingestion of the cysts, some of the worms may be sexually mature and producing ova. Usually it is not until the twentieth or twenty-fifth day or later that the majority have reached sexual maturity.

9. PREVENTION AND CONTROL OF CLONORCHIASIS IN MAN

As in the endemic districts of fasciolopsiasis, age-old customs of the people are particularly favorable for the propagation of the *Clonorchis* life-cycle. This is especially true in South China where fish are raised for sale and are fed fresh, fecal wastes. Fish from these "culture" ponds constitute the principal food of the country population and are sold not only in the larger towns in the immediate vicinity but are also shipped alive in large numbers to outside markets.

The chief methods which have been suggested to effect the control of clonorchiasis in man are: (1) the disinfection of feces; (2) the eradication of the snail host; (3) educational propaganda regarding the danger of consuming raw fish; (4) legislation prohibiting raw fish, or permitting only salt-water forms to be consumed raw; and (5) therapeutic prophylaxis.

Ammonium sulphate ($[NH_4]_2SO_4$) has been recommended as a practical ovicide against *Clonorchis*. One part of a 0.7 per cent solution to ten parts of feces kills the larva within the egg in one-half hour's time. Ammonium sulphate is more desirable than other chemicals tested as *Clonorchis* ovicides in that it is also a well-proved chemical fertilizer and has been in use in China in the mulberry districts for a considerable period. Eradication of the snail host, *Parafossarulus striatulus* and related species is difficult, if not impossible. These snails are usually found only in the muck at the bottom of the fish ponds and any chemical applied to the water to destroy them would probably never reach them. Chemicals which would kill the snails would also kill the fish crop. The snails show marked ability to withstand desiccation and are not killed during the draining of the ponds. Control efforts against the snail host in clonorchiasis are held to be impracticable. The most effective and feasible method of attack against this infection is the attempt by education and legislation to prevent the eating of raw or partly

cooked fresh-water fish. Such educational efforts should be incorporated into the school hygiene program of every school of the endemic centers. Popular lantern lectures, microscopic demonstrations, printed posters and dodgers are always effective and productive of immense good.

Therapeutic measures against clonorchiasis are at present of doubtful value. Antimony and arsenic compounds have given some encouraging results. Gentian violet administered per os has been found effective against *Clonorchis* in laboratory animals by Faust and Khaw (1926) but so far its practical application has not been tested.

Clonorchis infection in reservoir hosts seems to be of little importance as far as the infection in man in China is concerned. In endemic centers of human infection (South China) these hosts (cats and dogs) have been found to be rarely infected whereas in Central and North China the incidence is high in reservoir hosts but very low in man.

The practical solution of the problem of the prevention of clonorchiasis apparently can best be brought about by a careful educational propaganda whereby the population would be made aware of the cause of the infection and their habit of eating raw fish deprecated.

II. *Opisthorchis felineus* (Rivolta, 1884)

1. DISTRIBUTION

Opisthorchis felineus occurs frequently in man throughout East Prussia, Siberia, Annam and the Philippines and has been recorded from a number of carnivores. The normal habitat of the adult is in the gall ducts, but it has been found also in the intestine and the pancreatic duct.

The adult form is usually from 8 mm. to 11 mm. in length and 1.5 mm. to 2 mm. in breadth. The cuticula is smooth. The suckers are of about equal size and are separated from each other by one fifth to one sixth of the length of the body. Morphologically this species is quite similar to *Clonorchis sinensis* but the testes are lobed instead of branched as in *Clonorchis*. The eggs are small, light to dark yellowish-brown in color, with a sharply defined operculum at the more pointed pole, 30 μ long by 12 μ broad and contain a ciliated miracidium at oviposition.

2. LIFE-CYCLE

The life-cycle of *O. felineus* apparently closely follows that of *Clonorchis sinensis.* The ova hatch within the body of the snail, *Dreyssena polymorpha.* The cercariæ after leaving the snail host, penetrate the sub-dermal tissues of several species of fresh-water fish and there encyst, as in the case of *Clonorchis sinensis.* The bream, *Abramis brama,* the chub, *Idus melanotus,* the carp, *Cyprinus carpio,* the barbel, *Barbus barbus* and the tench, *Tinca tinca,* are known to harbor the encysted cercaria of this parasite in Rumania. Man and other definitive hosts become infected through eating raw or insufficiently cooked infected fish.

Two other species of the genus *Opisthorchis* have been reported from man but their presence in man is only incidental. *Opisthorchis viverrini* Poirier, 1886, is a normal parasite of the civet cat and has been discovered during autopsy in a Siamese. The worms were found in the bile ducts and the small intestine. Infection in the definitive host is incurred through eating raw fish.

Opisthorchis noverca Braun, 1903, has been reported twice from man in Calcutta, India. It occurs commonly in the pariah dogs of that country and its presence in man is but incidental. Another species of this genus, *Opisthorchis pseudofelineus* Ward, 1901, has been reported from cats in North America.

III. *Fasciola hepatica* (Linnæus, 1758)

I. HISTORICAL

Fasciola hepatica was apparently the first trematode parasitic in man reported after the introduction of the system of binary nomenclature, and its life-cycle has for years served in textbooks on zoölogy as a typical example of the development of DIGENEA. Its presence in man now is regarded as incidental, and the common or characterestic hosts are sheep, goats and other ruminants. This species is usually found in the biliary canals and the ducts of the liver and may occur as wandering parasites in the lungs and elsewhere. It is the cause of a serious disease in sheep known as "liver rot."

A large fluke which closely resembles *Fasciola hepatica* has been described as *Fasciola gigantica* from ruminants and once from man in Africa. It has a length up to 75 mm., a short cephalic cone and almost parallel sides. It is probably a variety of *F. hepatica.*

2. DISTRIBUTION AND FREQUENCY

F. hepatica is cosmopolitan in distribution and occurs where low, wet pastures and the presence of suitable snails make it possible for it to exist. In the United States, it occurs especially along rivers and tributary streams of the Atlantic and Pacific coasts and of the Gulf of Mexico. The states in which this fluke is most prevalent are Washington, Oregon, California, Texas, Arkansas, Louisiana, Alabama and Florida.

3. MORPHOLOGY

Fasciola hepatica (Figure 99) is flattened, heart-shaped in outline and measures from 20 mm. to 30 mm. long and from 8 mm. to 13 mm. in breadth and possesses a cephalic cone from 4 mm. to 5 mm. in length which is sharply differentiated from the body by a shoulder on each side. When in the living condition, it is brownish in color but becomes grayish when killed and kept in preservatives. The suckers are hemispherical and placed near to each other and are of about the same size. The pharynx is well developed and leads into the intestinal crura through the short esophagus. The intestinal crura extend to the caudal pole and are provided with numerous diverticula radiating outwards. The testes are greatly ramified and occupy the greater portion of the posterior part of the body, with the exception of the lateral and posterior borders. The ovary is also ramified and is situated lateral of the median line and in front of the transverse vitelline duct. The vitellaria are profusely developed and extend from the base of the cephalic cone to the extreme caudal pole, occupying nearly the entire posterior tip of the body. The uterus lies in

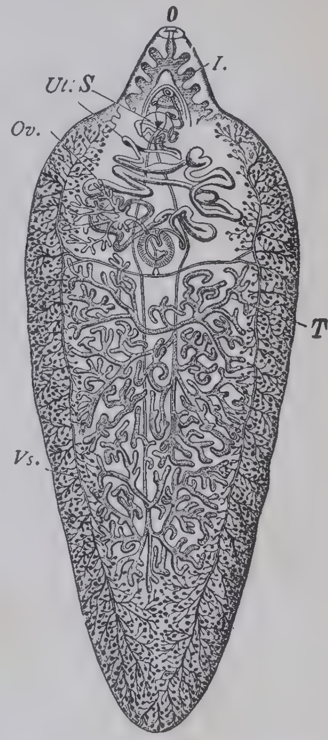


FIG. 99.—*Fasciola hepatica.* Showing internal structures of adult worm: *I.*, intestine; *Vs.*, vitellaria; *Ov.*, ovary; *O.*, oral opening; *S*, acetabulum; *T*, testes. (From Fantham, Stephens, and Theobald, *Animal Parasites of Man.* After Claus)

front of the ovary and is short in comparison to the rest of the body; a cirrus-sac is present and the genital pore is median, half-way between the oral sucker and acetabulum. The ova are yellowish brown, operculated, with development after oviposition and measure from 130 μ to 145 μ in length by 70 μ to 90 μ in breadth.

4. LIFE-CYCLE

The life-cycle of *Fasciola hepatica* closely parallels that of the large intestinal fluke of man, *Fasciolopsis buski.* The miracidium hatches from the egg in about three weeks after oviposition and finds its way into fresh-water snails of the genus *Limnæ* where the parthenogenetic generations develop. The cercariæ upon their escape from the snail host swim to the surface of the water and there encyst, the encysted forms then float freely on the surface film of water. The cercariæ may also attach themselves to a submerged blade of grass or aquatic vegetation for encystment. When these cysts are swallowed by sheep, or other suitable host animals, when drinking or with grass, the young flukes escape from their cyst wall in the small intestine and migrate up the bile duct to the liver for further growth to maturity. They may also penetrate the wall of the intestine and penetrate the liver from its surface.

5. PREVENTION

The manure from infected sheep should not be put on pasture land, especially if the pasture land is of low, wet ground. Swampy areas should be drained, filled in or fenced off. When the infection is present in the flock, treatment should be given to infected animals at the beginning of winter, after the danger of fresh infection is past. Safe drinking supplies should be provided for the animals, as the infective cysts may be free, floating in infected marsh lands as well as on vegetation. Copper sulphate in proportions of one part in from 500,000 to 2,000,000 parts of water is known to destroy the snail hosts within forty-eight hours, but does not kill the eggs of the parasite nor those of the snail. It is therefore necessary to repeat this treatment of ponds in from two to three months. This solution is not injurious to the higher plants and animals or for bathing, drinking or irrigation, but may injure some species of fish, especially the young. As wild herbivores may harbor this trematode, measures should be taken to exclude these animals from pasture lands.

IV. *Fascioloides magna* (Bassi, 1875)

1. MORPHOLOGY AND DISTRIBUTION

Fascioloides magna is commonly known as the "large American liver fluke," and closely resembles *Fasciola hepatica* (Figure 72, c) in structure except that it does not have a separate anterior portion or cephalic cone and the anterior end is bluntly rounded. The body is very large and may attain a length of 10 cm. It was first discovered in an European zoölogical garden in the wapiti elk. Its original home appears to be North America and it is known to occur in the liver and lungs of many herbivores, both domestic and wild. In the United States it is most prevalent near the Gulf of Mexico, especially in Arkansas and along the coast and river valleys of Texas. It also occurs along the west coast in both the United States and Canada and has also been found in Colorado, Wisconsin and New York. *F. magna* is a much more common parasite in cattle than in sheep. In cattle it seems to do but little damage aside from rendering the livers unfit for use as food. In sheep, it may do considerable harm and may be a cause of death.

2. POSITION IN THE HOST

Fascioloides magna occurs in the liver and lungs, commonly lying in cysts which contain one to several flukes and a quantity of dark-colored fluid filled with ova and débris.

3. PREVENTION

Although the life history of *Fascioloides magna* is not known, it is probable that it closely parallels that of *Fasciola hepatica* and measures that are used in the control of that parasite may equally apply to *Fascioloides magna.*

V. *Dicrocœlium lanceatum* (Stiles and Hassall, 1896)

Dicrocœlium lanceatum is the common European liver fluke of sheep and other herbivores. Outside of Europe it has been reported from Algeria, Egypt, Siberia, Turkestan, and North and South America. Its occurrence in man is incidental and has been observed only in a few European cases. It is characterized by its rather slender, elongate, flat body with more or less pointed ends.

Its length is 8 mm. to 10 mm. and 1.5 mm. to 2.5 mm. in breadth. The acetabulum is usually more highly developed than the oral sucker and is placed rather close to it. The cuticula is smooth. The pharynx passes into a moderately long esophagus and the intestinal crura are long and without branches. The genital pore is median and immediately anterior to the acetabulum. The copulatory organs are not highly developed. The testes are compact, nearly tandem to diagonal and lie directly posterior to the acetabulum. The ovary is median and lies immediately posterior to the testes. A seminal receptacle and Laurer's canal are present. The vitellaria are moderately developed and are lateral to the intestinal crura. The uterine loops are numerous, transverse and posterior to the ovary. The ova are of a deep brown color, operculated and slightly flattened on one side. They vary in size from 36 μ to 45 μ by 22 μ to 30 μ.

The life cycle of *Dicrocœlium lanceatum* is at present unknown.

VI. *Diseases Due to Liver Flukes*

A small number of flukes in the liver of the host usually gives rise to no appreciable disorder and probably the majority of individuals harboring these parasites might be classed as carriers. When they occur in large numbers, they do, however, produce definite injury to the host. They may form a mechanical obstruction of the bile ducts so that jaundice results or they may exert a pressure on certain veins causing ascites or enlargement of the spleen. The pancreatic ducts may also be obstructed. These worms also give off toxins which produce disorders far more serious than those caused by mechanical means. The severe anemia in clonorchiasis and "aqueous cachexia" in sheep infected with *Fasciola hepatica* and *Dicrocœlium lanceatum* are attributed to toxic origin. There is also danger from infection with bacteria of the bile and pancreatic ducts, during the migration of the young flukes, which may have a part in producing both the liver changes and general symptoms.

1. PATHOLOGY

At autopsy the liver of the infected host may be somewhat hypertrophied and on its surface are white blebs which represent the projections of distended bile ducts (Figure 100). Upon sectioning, numerous cavities with thickened sclerotic walls are found which are often filled with flukes and a brownish liquid containing thousands of ova. These cavities are hypertrophied bile ducts.

Microscopic study of stained liver sections show an intense proliferation of the biliary epithelium producing an adenoma-like tissue. The connective and muscular tissues of the bile duct undergo intense hypertrophy followed by sclerosis which constantly increases in extent until it may involve several canals and produce a sclerotic area of considerable size (Figure 101). In this zone there is considerable infiltration of lymphoid cells and eosinophiles. The hepatic parenchyma is encroached on by hypertrophied bile ducts, poisoned by toxins and poorly nourished and atrophied. Through the interference with circulation vascular areas resembling angioma may appear. Two cases have been reported of carcinoma developing at places in the liver most invaded by *Opisthorchis felineus* (Askanazy, 1904). The modified epithelium, however, usually shows no invasive properties.

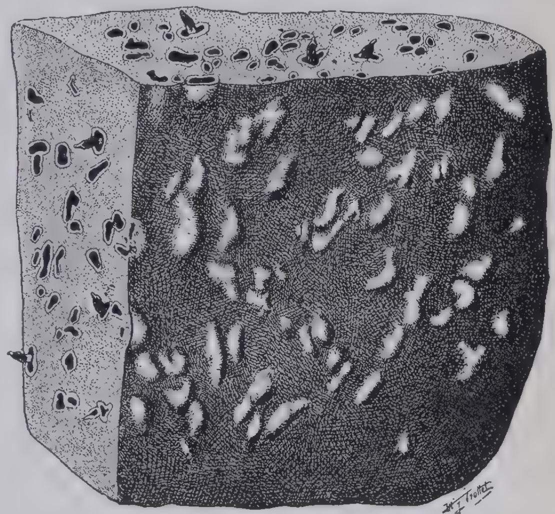


FIG. 100.—Human liver infected with *Clonorchis sinensis*. (From Brumpt's *Précis de Parasitologie*)

2. SYMPTOMS

Ordinarily light or moderate infections with liver flukes usually produce no clinical manifestations. There may be a morbid sense of hunger, an irregularity of the bowels and a feeling of pressure and pain in the epigastrium and right hypochondrium. In severe cases there is a bloody diarrhea and icterus. These symptoms are soon followed by anemia, emaciation, ascites and cachexia to which the individual finally succumbs. Sheep in the early stages of the disease are likely to put on fat and seemingly improve in condition apparently a result of a stimulation of the functions of the liver. The general course of the disease is very chronic and irregular.

3. HALZOUN

The inhabitants of North Lebanon are said to be commonly parasitized in the mouth and pharynx with liver flukes (*F. hepatica*). The infection is acquired by eating raw infected livers from which the flukes have escaped while in the mouth. They are found attached to the pharyngeal mucosa and to the adjoining parts and there cause

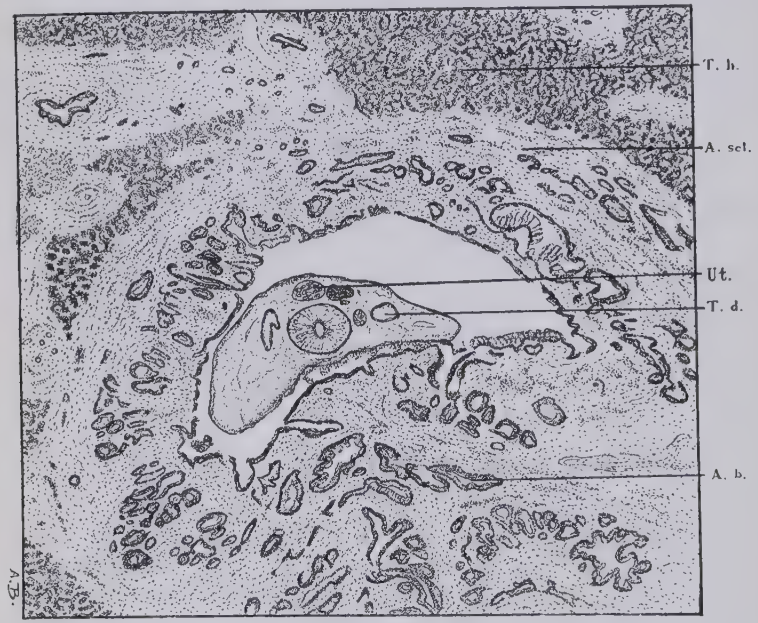


FIG. 101.—Lesions produced in the human liver by *Clonorchis sinensis.* T.h., liver tissue; A.scl., sclerotic tissue; Ut., uterus of the parasite; T.d., intestine of the parasite; A.b., biliary adenoma-like tissue. (From Brumpt's *Précis de Parasitologie*)

inflammation, congestion of the head, dyspnea, dysphagia and even death. The infection is known as "halzoun." It is generally mild, however, and the symptoms usually disappear after vomiting.

4. TREATMENT

Therapeutic treatment in cases of liver fluke infections appears thus far of doubtful value. Brug (1921) has, however, reported improvement in patients treated with tartar emetic and Shattuck (1924) found the stools of infected Chinese patients free from

Clonorchis ova one month after treatment with antimony and arsenic compounds. Faust and Khaw (1927) have observed that patients suffering from clonorchiasis improve upon antimony treatment and that ova may be absent from the stools for a period of three months and reappear later. Gentian violet was found by these authors to be clonorchicidal in therapeutic doses in experimental animals but so far its practical application has not been determined. Oleoresin of male fern and powdered kamala have been found satisfactory in the treatment of sheep for liver fluke infections. Kamala is, according to some writers, less efficacious than male fern. Recently, Montgomerie (1926) has reported exceptionally favorable results with carbon tetrachloride against flukes in sheep. This drug appears to be highly effective against the mature parasites, but immature worms appear to be unaffected by it.

CHAPTER XX

THE LUNG FLUKES

The trematodes known as "lung flukes" belong to the family TROGLOTREMATIDÆ (Odhner, 1914), Braun, 1915. These trematodes are characterized in general by a more or less thick, compact body with the ventral surface flattened and the dorsal surface arched. They are from 2 mm. to 13 mm. long. The musculature is weakly developed. The ovary and testes are lobed or coarsely branched and the uterine loops lie chiefly lateral of the acetabulum. They are parasitic in carnivores and birds and generally occur in pairs in cyst-like cavities in the lungs. The human representative of this family is *Paragonimus westermani.*

I. *Paragonimus westermani* (Kerbert, 1878)

1. HISTORICAL

Paragonimus westermani, commonly known as the human lung fluke, was first found in 1877 in the lungs of a tiger in the Zoölogical Gardens of Amsterdam, Holland, by the director, Westerman. These specimens were sent to Kerbert who described it under the name *Distoma westermani* (Kerbert, 1878). The lung fluke was first discovered in man in 1879 in the lungs of a Portuguese in Formosa. This specimen was described by Cobbold (1880) as *Distoma ringeri.* Manson, in 1880, described eggs found in the sputum of a Chinese suffering from hemoptysis. In 1883 Kiyono, Suga, Yamagata and Nakahama discovered the parasite in the lungs of a Japanese and, recognizing the disease caused by it, described the species as *Distoma pulmonale.* Leuckart (1889) reviewed the morphology of the specimens obtained from both man and the tiger and concluded they belonged to the same species; and Braun in 1899 established the genus *Paragonimus* with *Paragonimus westermani* as the type of the genus. *P. kellicotti* Ward, 1908, was found in 1894 in a cat in Michigan by Ward and later in a dog in Ohio by Kellicott. Stiles

and Hassall (1900) found the lung fluke a frequent parasite in hogs, slaughtered in Cincinnati, Ohio, and, although these authors recognized the possibility that these worms might represent a distinct variety, they were looked upon as being identical with the Asiatic form. Ward and Hirsch (1915) after a morphological study of the American form with material from man in the Orient, and with three specimens of Kerbert's material from the tiger, concluded that there are three species of the mammalian lung flukes: (1) the tiger form, *Paragonimus westermani;* (2) the human form, *P. ringeri;* and (3) the American form from the dog, cat and pig, *P. kellicotti.* Ward and Hirsch based the specific differences mainly on the size, shape and arrangement of the cuticular spines. Kobayashi (1919) carefully reviewed the structure of the lung flukes from man and lower animals of Japan and Korea and found that individual variations are apparently greater than the specific differences recorded by Ward and Hirsch (1915) and concludes that there is only one species of lung fluke to which the name *Paragonimus westermani* must be given. Later, Vevers (1923) also found differences in the cuticular spines and recognizes four distinct species: (1) *P. westermani;* (2) *P. ringeri;* (3) *P. kelicotti;* and (4) *P. compactus.* The last named species was described from *Viverra mungos,* India, by Cobbold in 1859. Authorities still disagree as to the identity of the species of *Paragonimus,* and this question can only be settled by further study.

Life history studies on *Paragonimus westermani* were first made by Nakagawa (1915). He obtained the adult flukes by feeding experimental animals fresh-water crabs, *Potamon obtusipes,* in which he found encysted trematode larvæ. Further studies on the first intermediate host and the development of cercariæ were made by Nakagawa (1915-1919), Yokogawa (1917), Kobayashi (1918-1921), Miyairi (1919) and Ando (1917). These authors have found that various species of snails of the genus *Melania* serve as the intermediate host of this parasite, and have also determined its course and development within the body of the final host.

2. DISTRIBUTION AND FREQUENCY

Paragonimus westermani has a wide geographic distribution and occurs more or less frequently in man in local districts of Japan, Korea, Formosa, China and the Philippine Islands. A number of cases have been noted in North America among Oriental immigrants but no definite, native infections in man have been found in the

United States. Endemic areas of *Paragonimus* infection in man have been reported from Yucatan and Peru. In Japan the infection is largely limited to certain mountainous districts along streams where it is estimated that about 2 to 10 per cent of the population suffer from the disease. It is also widely distributed in Korea and Formosa, but apparently is quite rare in China and the Philippine Islands. Arce (1915) reports that the disease in Yucatan has increased considerably in recent years on account of the immigration of Chinese and Japanese laborers. The parasite is also found in cats and dogs of Venezuela but no cases have been recorded for man. *Paragonimus westermani* also occurs in lower animals (dogs, cats and pigs) wherever the infection in man occurs, and it is probable that its distribution in these hosts is much more widespread than in man. *Paragonimus westermani* has apparently no very definite specificity since it has been recorded from man, cat, dog, tiger, mountain lion, fox, marten, badger and weasel. Monkeys have been experimentally infected as well as rabbits, guinea-pigs, rats and mice but the development, in the last named animals, does not proceed to sexual maturity.

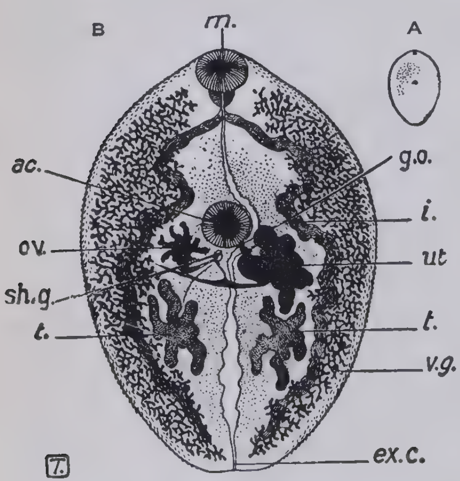


FIG. 102.—*Paragonimus westermani.* A, Natural size. B, detail of internal anatomy: *m.*, mouth surrounded by oral sucker; *ac.*, ventral sucker; *ov.*, ovary; *sh.g.*, Mehlis' gland; *t.*, testis; *g.o.*, genital pore; *ut.*, uterus; *v.g.*, vitellaria; *ex.c.*, excretory pore. (From Manson-Bahr's *Manson's Tropical Diseases*)

3. MORPHOLOGY

The living specimens of *Paragonimus westermani* have no very definite shape as they constantly stretch outward and contract. They may appear more or less like a ribbon when fully elongated, or spoon-shaped when one pole of the body is contracted and the other elongated; or as a sphere when completely contracted. When killed and preserved they have an oval or elliptical form, resembling closely a coffee grain in both size and shape. They are of a reddish brown to a slate color when first removed from the body, but soon become grayish on exposure. The oral sucker is situated at the

anterior extremity of the body and opens anteriorly in well extended specimens. In contracted specimens the mouth is ventral. The suckers are usually of about equal size, ordinarily slightly less than 1 mm. in diameter. The ventral sucker, or acetabulum, is situated somewhat anteriorly to the middle of the body and often lies completely invaginated in the body leaving a relatively narrow external opening visible from the body surface. The genital pore lies on the mid-ventral surface close to the posterior margin of the acetabulum. The arrangement of the internal organs is shown in Figure 102.

4. LIFE-CYCLE

The eggs of *Paragonimus westermani* usually escape from the host in the host's sputum. Because of their dark color the sputum often appears rusty, especially when they occur in large numbers. In case the host swallows his sputum these ova may also be found in the host's feces. The eggs of this species are oval, yellowish-brown in color and have a thick shell (Figure 103). The operculate end of the egg is always the broader and the shell at the opposite end often has a small nodule projecting from it. The eggs have been found to vary considerably in size, even when they are obtained from a single host, varying in length from 85 μ to 100 μ by 50 μ to 67 μ in breadth. They show no development when found in fresh sputum, the fertilized cell is in the single-cell stage, and is surrounded by several yolk balls. The development of the miracidium is slow and may require from four to six weeks before it escapes from the shell. Under optimum conditions hatching of the miracidium takes place in about sixteen days.

FIG. 103.—Eggs of *Paragonimus westermani* in sputum. (From Manson-Bahr's *Manson's Tropical Diseases*)

At least six species of fresh-water snails of the genus *Melania* may serve as the first intermediate host of *Paragonimus westermani.* Of these, *Melania libertina* in Japan and *Melania gottschei* in Korea are perhaps the most important species in the propagation of *Paragonimus* as they are the common fresh-water snails of these countries.

The miracidium of *Paragonimus westermani* upon penetrating the tissues of its snail host, loses its cilia and becomes a sporocyst, just under the epidermis. As this sporocyst increases in size, several germ balls appear in its body cavity. One of these germ balls develops more rapidly than the others and produces a redia. Usually only one redia with several germ balls are present at one

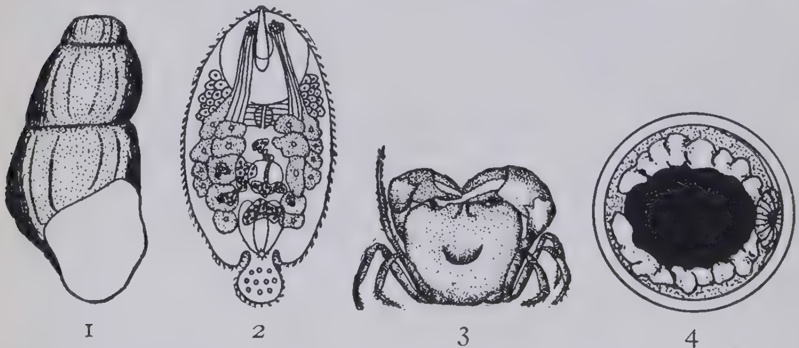


FIG. 104.—Life history stages of *Paragonimus westermani.* 1., *Melania ebenina,* the first intermediate host in China (x 1½). (After Faust); 2., Cercaria from the first intermediate host (magnified). (After Faust); 3., *Potamon dehaani,* a second intermediate host (one-fourth natural size). (After Faust); 4., Encysted metacercaria from second intermediate host. (x 60) (Original)

time within the sporocyst, but probably after the escape of the first redia others develop in a similar manner. Further development of this redia, the mother redia, may take place near the sporocyst or it may migrate toward the liver of the snail. The mother redia produces daughter rediæ, which, after their escape from the mother redia, migrate into the liver of the snail and there produce cercariæ. After the escape of the cercariæ from the snail they penetrate into the body of several species of fresh-water crabs, *Potamon obtusipes, P. dehaani, P. sinensis, Sesarma dehaani, Eriocheir japonicum* and the crayfish, *Astacus japonicus,* and there encyst in the liver, muscles and especially in the gills. Man and other mammals which serve as the final hosts become infected by eating the raw infected flesh of these crustaceans.

The free cercariæ of *Paragonimus westermani* are character-

ized by an elongate oval body with the anterior end slightly wider than the posterior and provided with a small stylet. The tail is stumpy and would be included with the microcercous cercariæ, according to Lühe's classification (page 209).

The fully developed, encysted cercaria (metacercaria) within the body of the crab is usually spherical having a diameter from 0.35 mm. to 0.47 mm. The wall of the cyst is very thick and tough and is surrounded by an outer membranous sack which is produced by a reaction of the host's tissue against the parasite. Within the living cysts the organs of the larvæ are distinctly visible. Life history stages of *Paragonimus* are illustrated in Figure 104.

Nakagawa (1918) found that the encysted larvæ of *Paragonimus* were killed when the crabs were roasted until the muscles turned white and when the crabs were kept in water in 55° C. for five minutes. He also noted that when they were freed from the tissues of the crab they could survive a 2 per cent hydrochloric acid solution for three hours. One hour in vinegar was sufficient to kill them, and nine hours was sufficient to kill all the larvæ when the crab gills containing the cysts were placed in soy sauce. Yokogawa (1917) found that a 10 per cent salt solution killed the encysted larvæ in one hour and a 5 per cent salt solution killed them in from two to three hours.

5. POSITION IN THE BODY

The adult of *Paragonimus westermani* is found most frequently in cysts near the surface of the lungs of the final host. The cyst wall consists of a layer of connective tissue and is produced by the host as a reaction against the parasite. Besides the worm, the cyst usually contains an exudate with eggs of the parasite and Charcot-Leyden crystals. In other instances the worm may have been dead for some time and only its "mummy" remains. In man these cysts usually contain a single worm but in dogs and other mammals they commonly contain two or more.

The adult parasites have been found also in the abdominal and pleural cavities, the brain, orbit and eyelids, omentum, pericardium, anterior longitudinal sinus, spleen and vertebral column. Immature specimens are always encountered outside of the lungs, in the peritoneal and pleural cavities or in soft tissues but never in the lungs. Even if they are directly introduced when immature into the lungs by way of the jugular vein, they escape to complete their development elsewhere.

6. THE MIGRATORY COURSE OF THE LUNG FLUKE IN THE BODY OF THE FINAL HOST

While it is possible that some infections are acquired from drinking water containing living cysts which have been freed from crabs, it is very probable that the majority of infections with *Paragonimus* are incurred by a direct ingestion of the cysts from crustaceans serving as second intermediate hosts, either in connection with the handling of crabs while preparing them for food, or more especially by eating them raw or imperfectly cooked.

After the entrance of the encysted larvæ within the body of the final host, they show a remarkable tendency to migrate, and invade tissues other than the lungs until they are sexually mature. The course of the young flukes in the body of the final host has been studied in detail by Yokogawa (1919) and other Japanese scientists.

The encysted cercariæ, after being swallowed with the flesh of the crab, escape from their cysts in the small intestine of the host. Within several hours, by their own leech-like movements, they penetrate through the intestinal wall and reach the abdominal cavity. The worms pass through the middle and posterior regions of the small intestine. Their movements seem to be influenced by the resistance of the tissues since they penetrate the mucous membrane along the long axis of the intestine, and after passing through the submucosa burrow into the muscular layers moving with the long axes of the fibers. They then make their way along the abdominal cavity and penetrate the diaphragm. They may live for a long time in the abdominal cavity and make their way into other organs before reaching the diaphragm. Therefore, at the time of piercing the diaphragm they may be in an early stage of development or at any stage up to sexual maturity. When young they pass through the muscular parts of the diaphragm pushing aside the muscle fibers. When older they seem to prefer the sinewy parts. They have been found in the chest cavity as early as seventy hours after ingestion. They usually remain much longer in the body cavity, however, and it may be a hundred days or more before they penetrate the diaphragm.

During this time they may burrow into various organs, such as the liver, omentum, mesenteries or spleen. Most frequently they migrate into the liver, probably because it is large and soft and lies directly in their general course. When they enter the liver, they only penetrate a short distance and then turn and escape

making characteristic, blind alleys. Most of the young flukes seem to reach the diaphragm by way of the space between the liver and the abdominal wall, since the paths of the worms in the liver are found most frequently on the anterior margin of its upper surface. There is no evidence that the young worms ever migrate to the lungs by way of the blood or lymph vessels of the intestinal wall, omentum or mesenteries. About twenty days or more after infection, the worms enter the chest cavity and penetrate into the lungs. Not all the worms which enter the abdominal cavity will migrate into the diaphragm, however, nor do all those which enter the chest cavity penetrate the lungs. Accordingly, in heavy infestations in experimental animals, some worms have been found almost always in the abdominal cavity and surrounding organs and in the pleural cavity and may reach maturity in these locations.

Some of the worms may migrate to the brain but apparently do not remain in this tissue for their development. The course to the cranial cavity is believed to be along the soft tissues of the neck and through the large foramina, especially the jugular foramen, since in human cases, the pathological changes in the brain are almost always in the temporal or occipital lobes near the jugular foramen.

II. *Diseases Caused by Lung Flukes*

I. PATHOLOGY

The adult flukes are ordinarily found in the lungs of the final host but they may be found in most every tissue, as pointed out in an earlier paragraph. In the human lungs the cysts are usually flat and contain but one parasite, and only rarely are two found together in one cyst. In the post-mortem examinations of the human lung the cysts are not always easily located since they do not, as a rule, project from the lung's surface. In the lungs of cats, dogs and other animals, however, they stand out clearly as dark-red or brown bodies on the surface of the lung. They are about the size of a filbert and usually contain two worms. The number of flukes in a single human host has usually been under ten and only in a few exceptional cases have more than twenty been found. In dogs and cats, however, the numbers present are usually larger. These cysts represent dilatations of the bronchi, or bronchioles, and contain, besides the worm, a brown exudate containing ova of the parasite, which is the same material that constitutes the characteristic sputum, and Charcot-Leyden crystals. Sometimes only

the "mummy" of the parasite remains and in other instances the cysts may undergo caseation and resemble tubercles. Abscesses and ulcerations occur frequently. The septa between the lesions may break down and thus give rise to cavities which resemble a dilated bronchus. Extensive cirrhotic changes and emphysema may also be associated with these lesions.

2. SYMPTOMS

Patients suffering from paragonimiasis have a chronic cough which is usually most urgent in the morning upon rising. Considerable blood-stained or purulent sputum is ejected in which the ova of the parasite may be found by microscopical examination. The hemoptysis is usually trifling, but in some instances it may be so great as to threaten life. Râles are usually not discoverable. If the infection is abdominal, the abdominal wall feels hard to the touch and there is more or less tenderness. When certain organs are acutely involved, appendicitis, enlargement of the prostate, epididymitis, cirrhosis of the liver and diarrhea from intestinal ulceration may result. Cerebral infections are frequently associated with a peculiar form of Jacksonian epilepsy which may result in paralysis, visual disturbances or aphasia, which are also characteristic of cerebral infections with certain tapeworm larvæ. Paragonimiasis may also be of a more or less generalized type associated with fever, enlargement of the lymph nodes and cutaneous ulcerations.

3. DIAGNOSIS

The diagnosis of *Paragonimus westermani* is established by the finding of the characteristic ova in the sputum, feces or in fluids obtained by puncture. X-rays and serum reactions may, however, aid in its determination.

4. TREATMENT

Thus far no specific treatment is known for paragonimiasis but iodide of potash is recommended by Musgrave (1907), and Ando (1917) has reported that emetine reduces the sexual activity of these parasites.

5. PREVENTION AND CONTROL

The chief methods which have been suggested are (1) the disinfection of expectorated sputum, (2) the eradication of the various

species of *Melania* snails which serve as intermediate hosts, (3) the eradication of the crabs and crayfish which serve as second intermediate hosts, (4) the prohibition of the use of river water in the infected districts, and (5) the prohibition of eating raw or imperfectly cooked crabs.

Disinfection of sputum of the infected individuals while advisable is not effective as a method of control because the infection is widespread in various domesticated and wild animals. The eradication of the first and second intermediate hosts is exceedingly difficult if not impossible.

The most effective and feasible method of attack against this disease is the attempt by education or legislation to prevent the eating of raw or partly cooked crabs. Much publicity has been given to the danger of such food habits in the endemic areas of Japan, Korea and Formosa, and the local governments in the endemic areas of these countries have passed laws prohibiting the eating of raw crabs. Not sufficient time, however, has elapsed to determine what effect this legislation has had on the prevalence of this parasite.

CHAPTER XXI

THE BLOOD FLUKES

I. *The Family Schistosomatidæ* (Looss, 1899; Poche, 1907)

The family SCHISTOSOMATIDÆ, or blood flukes, differ from all other trematodes described thus far in that the sexes are separate, with striking sexual dimorphism; the eggs are not operculate, and the cercariæ are of the forked-tail type which actively penetrate into the host through the skin. They inhabit the venous system of mammals and birds in various tropical and subtropical countries.

The blood flukes are perhaps the most important trematodes parasitic in man; they cause diseases known as bilharziasis, endemic hematuria or urinary schistosomiasis, and intestinal schistosomiasis, katayama disease or schistosomiasis of the Far East.

1. HISTORICAL

Schistosomiasis is a very old disease. In Egypt, hematuria, a common symptom of Egyptian schistosomiasis, has been recognized since the earliest times and the medical papyri contain prescriptions against it. The actual evidence of its presence has recently been brought out by Rüffer (1910) who discovered ova of the parasites in mummies of the twentieth dynasty, 1250-1000 B.C. The discovery of the parasite itself was not made, however, until 1851 by Bilharz. Bilharz later established the relation between the blood flukes and the hematuria and dysentery with the accompanying lesions of the bladder and intestine which were so frequent in Egypt. This disease was then known, and is now referred to as "bilharziasis." This work of Bilharz established, for the first time, a connection between a trematode parasite and a human disease. Two types of eggs were found, one with a terminal spine and the other with a lateral spine, but they were considered as from a single species of parasite which produced both bladder and rectal types of the disease. Much confusion followed because of the presence of ova with lateral and terminal spines and it was not until 1907

(Sambon, 1907) that the two species were definitely separated; the separation being based on (1) the position of the spines on the eggs, (2) the different anatomical habitat, (3) differences in pathogenicity and (4) differences in geographical distribution. Sambon retained the name *Schistosoma hæmatobium* for the urinary type of ova with the terminal spine and established a new species, *Schistosoma mansoni,* for the rectal form with lateral spined ova.

In Japan, schistosomiasis is a disease probably as old as Egyptian bilharziasis but exact knowledge regarding it is of quite recent date. In ancient times there was recognized an endemic disease in certain districts of Japan which produced swelling of the liver and spleen. A description of this disease was written in 1847 by Fujii under the name of "Katayama disease." Later Yamagiwa (1890), Fujinami (1904) and others found eggs at autopsies in the liver, mesenteries, lungs and brain of man, and much discussion among the medical men of Japan followed in regard to the relation of the ova of this unknown parasite to the endemic "Katayama disease."

The first actual relation of the causative agent to the infection was obtained by Katsurada (1904). Katsurada found the eggs in the feces of a patient suffering from this disease and a worm in the portal vein of a cat. He also found eggs in the liver of the cat and reported that these were the same eggs that were found in the human disease, and that the worm produced the eggs and was the cause of the disease. He named the worms *Schistosomum japonicum*. Later in the same year the worm was found in the portal vein of a man who had died of the infection.

The discovery of the intermediate stages of the schistosomes and the method of entrance into man is of very recent date. All early attempts to infect species of snails or insects with *Schistosoma* were unsuccessful and after repeated attempts to find the intermediate host and larval stages of the Egyptian blood fluke, Looss (1894-1908) advanced the hypothesis that no intermediate host was needed in the life-cycle of this genus, and that man was infected by the penetration of the miracidium through the skin; and, according to this hypothesis, the intermediate stages developed in the liver of man. Experimental attempts to prove this hypothesis failed and were explained away by stating that since man was the only host for this infection experiments on other animals were without significance. This hypothesis received the support of many parasitologists and undoubtedly delayed the final discovery of the life-cycle of the schistosomes.

In 1909 Fujinami, Katsurada, Nakamura and others proved experimentally that infection with *Schistosoma japonicum* did come about through the skin and adequate protection of the skin was suggested as a prophylactic measure. It was not until 1913, however, that the infective agent was discovered. This discovery was made by Miyairi and Suzuki who were not only able to infect mammals from cercariæ from Katayama snails, but also observed the penetration of the hatched miracidia into the same species of snail and followed the development of the larval stages within the snail.

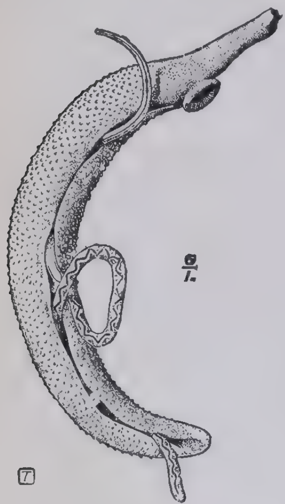


FIG. 105.—*Schistosoma hæmatobium.* Male carrying the female in the gynæcophoric canal. (From Manson-Bahr's *Manson's Tropical Diseases*)

This discovery led to similar investigations on the Egyptian flukes, *Schistosoma hæmatobium* and *S. mansoni* by Leiper (1915-1918) who found the intermediate hosts of these species and studied the larval stages. Further investigations on the life-cycle of *Schistosoma mansoni* have been carried on in the New World by Iturbe and Gonzalez (1917) and Lutz (1919). The names of various snails which may serve as intermediate hosts for the schistosomes of man are given in Table V, page 269.

2. POSITION IN THE HOST

All of the schistosomes are parasites of the venous system of their final host. *Schistosoma hæmatobium* inhabits especially the mesenteric branches of the portal vein, the vesicoprostatic, the pubic and uterine plexuses and the vesical veins. *S. mansoni* is found most commonly in the inferior and superior mesenteric veins, the hemorrhoidal plexus and the portal system. The habitat of *Schistosoma japonicum* in the human body is similar to that of *S. mansoni.* The worms are usually mated and headed against the blood current.

Schistosoma japonicum occurs as a natural infection in a relatively large number of mammals, including man, cat, dog, pig and cattle and can be readily transmitted to laboratory animals, cats, mice, monkeys, guinea-pigs and horses. *Schistosoma hæmatobium* has been observed as a natural infection in the sooty monkey, and,

TABLE V.

DISTINGUISHING FEATURES OF THE HUMAN SCHISTOSOMES

	S. hæmatobium	*S. mansoni*	*S. japonicum*
Adult male	Size, 12-14 mm. long Cuticula finely tuberculated Intestinal crura unite late so that united region of intestine is short Testes large, 4 in number	12 mm. long Cuticula grossly tuberculated Intestinal crura unite early so that united region of intestine is long Testes small, 8 in number	9-22 mm. long Cuticula non-tuberculated Intestinal crura unite far back, united region being one-fifth to one-sixth of body length Testes slightly lobate, 7-8 in number
Adult female	Size, 20 mm. long Uterus long and voluminous and contains a number of eggs Ovary in posterior half of body	14-15 mm. long Uterus short, contains usually from 1-3 eggs at a time Ovary in anterior half of body	12-26 mm. long Uterus well-developed, occupies about half of postacetabular region, contains 50-300 eggs Ovary about the middle of the body
Eggs	Terminal spine, 150 x 60, usually deposited in veins of bladder, escape with urine	Lateral spine, 150 x 60 usually deposited in veins of rectum, escape with feces	Abbreviated spine, 80 x 65, deposited in portal system, enter intestine higher than with *S. mansoni*
Cercariæ	Cephalic glands. Three pairs small nuclei and with single acidophilic reaction Head gland—absent	Six pairs cephalic glands of which two pairs are acidophilic with large nuclei while four pairs are basophilic with small nuclei Head gland—absent	Five pairs with large nuclei, acidophilic reaction Single head gland, lying within the oral sucker complex
Intermediate hosts	*Bulinus contortus* (Egypt) *B. dybowski* (Egypt) *B. innesi* (Egypt and Sudan) *Physopsis africana* (S. Africa) *Planorbis dufourii* (Graells) (Portugal)	*Planorbis boissyi* (Egypt) *P. olivaceous* (Brazil and Dutch Guiana) *P. centimetralis* (Brazil) *P. guadelupensis* (Venezuela and Antigua) *P. antiguensis* (West Indies) *Physopsis africana* (S. Africa)	*Blanfordia nosophora* (Japan and China) *B. formosana* (Formosa) *Hemibia hupensis* (Yangtse Valley)

under experimental conditions, can be established in laboratory animals. *Schistosoma mansoni* is, however, known to infect man only.

3. MORPHOLOGY OF THE ADULT WORMS

The male worms are characterized by a body which is widened and infolded behind the ventral sucker into the so-called "gynæcophoric canal" in which the female is held at the time of copulation (Figures 105, 106, 107). It is usually light gray or whitish in color and varies from 9 mm. to 22 mm. in length, according to the species, (see Table V). Extended specimens in the veins may

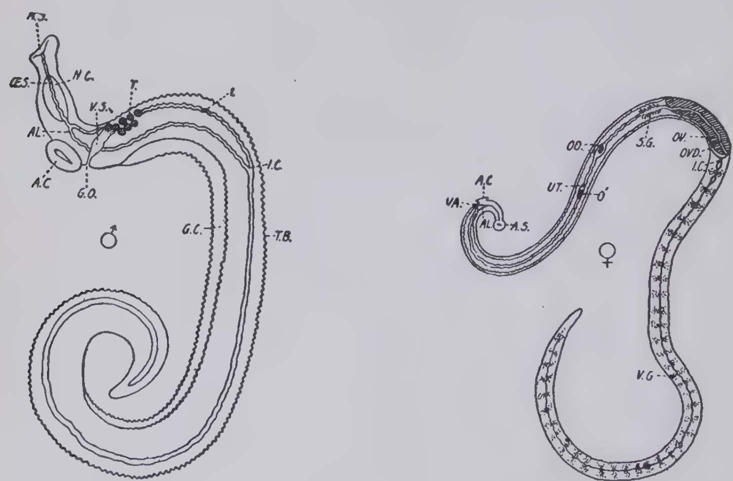


Fig. 106.—*Schistosoma mansoni,* male and female. *A.C.,* ventral sucker; *A.L.,* bifurcation of alimentary canal; *A.S.,* oral sucker; *G.C.,* gynæcophoric canal; *G.O.,* genital pore; *I.,* intestine; *I.C.,* union of intestinal crura; *N.C.,* nerve cord; *O,* egg; *ŒS.,* esophagus; *OO.,* oötype; *OV.,* ovary; *OVD.,* oviduct; *S.G.,* Mehlis' gland; *T.,* testes; *T.B.,* tuberculations; *UT.,* uterus; *VA.,* vagina; *V.G.,* vitelline glands; *V.S.,* seminal vesicle. (x 10). (From Manson-Bahr's *Manson's Tropical Diseases*)

have a length up to 30 mm. The suckers are large and prominent, the oral sucker is funnel-shaped and the acetabulum is distinctly pedunculate and is usually larger than the oral sucker. In the digestive system of both the male and female worms, the mouth is somewhat ventral. The intestine branches immediately in front of the acetabulum and reunites later in the posterior portion of the body. The length of the united posterior portion forms a characteristic for the species (see Table V). The excretory system consists of two longitudinal canals which open into the excretory pore which is placed somewhat dorsally at the posterior end. The male reproductive system is made up of from four to eight testes which lie posterior and dorsal to the acetabulum. The vasa efferentia unite

to form an elongated seminal vesicle which opens to the exterior through the genital pore, situated immediately below the acetabulum in the median line. There is no cirrus-sac. The genital pore is enlarged at the time of copulation, and is applied to the female genital pore for the transfer of spermatozoa.

The female worms are darker in color and vary from 14 mm. to 26 mm. in length, according to the species (see Table V). She is cylindrical and pointed at each end. The middle portion of her body is generally infolded in the gynæcophoric canal of the male and the anterior and posterior portions are free. The posterior free portion is often of a dark brown color. The digestive system is similar to that of the male except as modified by the great difference in body shape. The intestinal ceca are large and prominent and full of dark pigment. The union of the intestinal ceca is made immediately back of the ovary. The female reproductive system consists of one ovary situated behind the middle of the body in front of the union of the intestinal ceca. The oviduct arises from the posterior pole of the ovary and as it passes forward is joined by the vitelline duct. The vitellaria occupy the posterior part of the body. The oviduct leads into Mehlis' gland from which the uterus passes forward and opens at the genital pore situated immediately posterior to the acetabulum. Differences in structure of the three species of *Schistosoma* occurring in man are given in Table V.

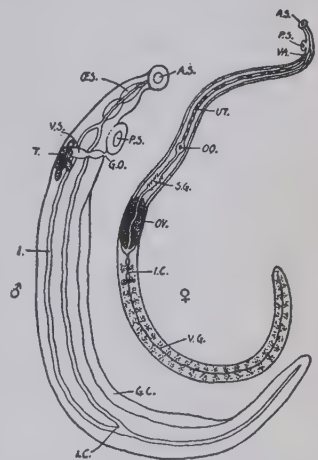


FIG. 107.—*Schistosoma japonicum*, male and female; for lettering see legend to Fig. 106 (x 10). (From Manson-Bahr's *Manson's Tropical Diseases*)

4. GEOGRAPHICAL DISTRIBUTION

As far as our knowledge goes, Japanese schistosomiasis is limited as an endemic disease to the Far East, being quite prevalent in some parts of Japan, Southern Formosa, Philippine Islands. It is especially prevalent and of economic importance in the rice-growing regions of the Yangtze Valley in China.

The records of the distribution of schistosomiasis in Africa are to some extent confused by the fact that the distinction between

Schistosoma hæmatobium and *S. mansoni* is of comparatively recent date, although both the rectal and vesical types of the disease were early recognized. Both types are prevalent in Egypt, especially along the Nile Valley. *Schistosoma mansoni* is probably lower in incidence than *S. hæmatobium.*

In South Africa, *Schistosoma hæmatobium* is very prevalent and has a wide distribution, but *S. mansoni* does not occur as frequently. In the Belgian Congo, *Schistosoma mansoni* is more prevalent and *S. hæmatobium* is quite rare.

Both species are found in North Africa but *S. hæmatobium* is especially common in Morocco, Algiers and Tunis, as well as in Egypt.

Schistosoma hæmatobium is also met with outside of Africa occurring in Portugal, Mauritius, Mesopotamia, Madagascar and Australia.

It seems probable that *Schistosoma mansoni* was introduced into the western hemisphere with negro slaves from Africa, and it is now endemic in Martinique, Guadeloupe, Porto Rico, French and Dutch Guiana, Venezuela and Northern Brazil. The failure of *S. hæmatobium* to get a foothold in the New World can possibly be explained by the failure of the parasite to find a suitable intermediate host; or it may be that a greater incidence of *S. mansoni* occurred in the regions from which the slaves came.

5. LIFE HISTORY

In order to get the eggs to the outer world the female schistosome moves down against the blood stream as far as the size of the smaller venules will permit, deposits one egg at a time and withdraws in the vessel after each egg is deposited so that the vessel has the appearance of a chain of beads, the eggs lying in a single row in the vessel. In the case of *Schistosoma mansoni* and *S. japonicum* the migration is toward the intestine and rectum, while with *S. hæmatobium* it is generally to the urinary

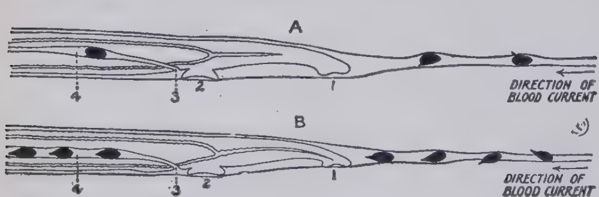


FIG. 108.—Diagram representing deposition of eggs (A) *S. mansoni* and (B) *S. hæmatobium* in blood vessels, and their passage to exterior. 1, oral sucker; 2, ventral sucker; 3, vulva; 4, uterus with contained eggs. (From Manson-Bahr's *Manson's Tropical Diseases*)

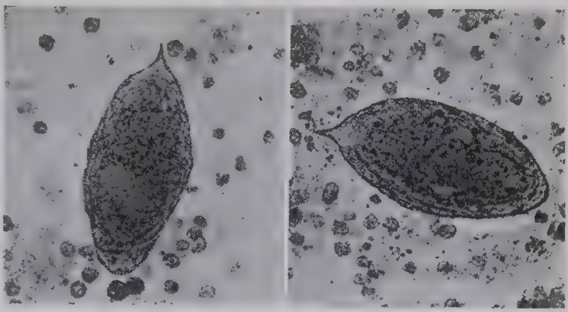


FIG. 109.—Ova of *Schistosoma hæmatobium* with pus corpuscles in urine (x 250). (From Todd's *Clinical Diagnosis*, W. B. Saunders Company)

bladder. Fairley (1920) has observed that the paired worms travel against the blood stream to the furthermost possible point, where the female leaves the male, and moves further into the vessel, too small to accommodate the male, by means of the suckers, until the smaller venule is stretched to the utmost; she then deposits one egg at a time and withdraws in the vessel after each egg is deposited. When the worm retires the vein

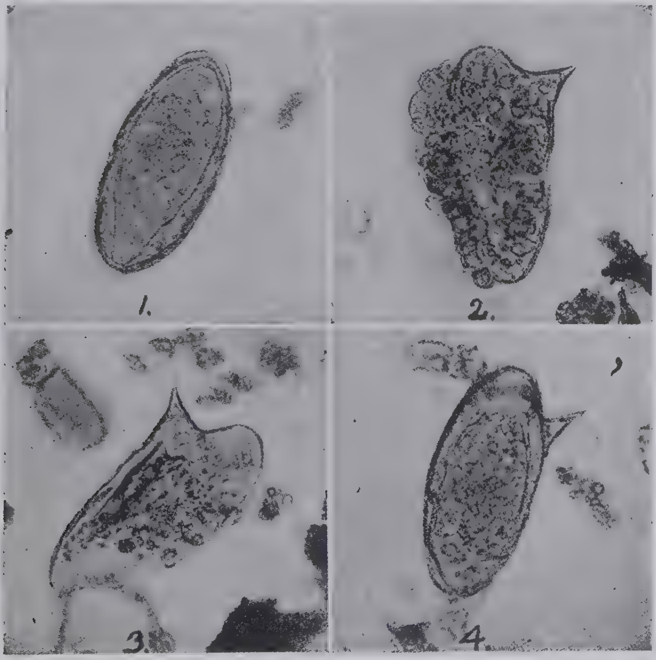


FIG. 110.—Ova of *Schistosoma mansoni:* 1, with spine out of focus; 2, in a clump of red blood cells; 3, apparently unfertilized; 4, usual appearance (x 250). (From Todd's *Clinical Diagnosis*, W. B. Saunders Company)

contracts to its normal dimensions and the returning blood drives the spine of the egg into the wall of the vein. The eggs then tend to work their way through the mucosa of the bladder, or rectum, as the case may be, so that they are eventually discharged with the urine or feces (Figure 108). Faust and Meleney (1924) have observed that the female of *S. japonicum* does not leave her partner during this act of egg laying. The eggs of *S. hæmatobium* (Figure 109) usually are passed with the urine and frequently with the feces while the eggs of *S. mansoni* (Figure 110) usually are passed with the feces and only rarely with the urine. The eggs of *S. japonicum* (Figure 111) are passed from the host only in the feces. The ova of *S. hæmatobium* are characterized by a prominent terminal spine and are about 150 μ long and 60 μ broad and the eggs of *S. mansoni* have a distinct lateral spine and are of about the same size as those of *S. hæmatobium*. The eggs of *S. japonicum* are smaller, however, 80 μ by 65 μ and are characterized by an abbreviated, lateral spine.

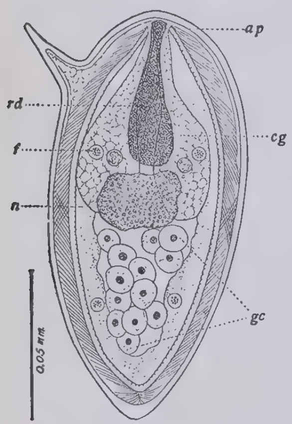


FIG. 111.—Miracidium of *Schistosoma mansoni* within the egg, from neural surface. *ad.*, anterior ducts; *ap.*, anterior papilla; *cg.*, cephalic gland; *exp.*, excretory pore; *f.*, flame cell; *gc.*, germ cell; *m.*, central nervous mass; *rd.*, rudimentary digestive-sac. (After Cort)

In all three species of the human schistosomes the egg contains a more or less fully developed, heavily ciliated, miracidium, when it reaches the exterior. The eggs hatch in water within a very few hours and the miracidia (Figure 111) immediately set out for the specific intermediate hosts. Under most favorable conditions the miracidium does not live more than forty-eight hours unless it reaches its snail host.

This miracidium differs from the miracidium of *Fasciolopsis buski* in that it does not lose its cilia when penetrating the snail host but utilizes them in making its way deeper into the tissues. At the base of the gills, or in the tentacle or "horn" of the snail, the cilia are lost within twenty-four to forty-eight hours after penetration, and the miracidium becomes a simple sac, the mother sporocyst. Elongated daughter sporocysts develop from the germ cells within the mother sporocyst, which, when mature escape through the wall of the mother sporocyst and make their way to the digestive gland or liver of the snail. Here the daughter sporocysts increase in size, and when they are fully developed they contain a

large number of forked-tail cercariæ in different stages of development. The fully developed cercaria (Figures 112, 113) pushes out of the daughter sporocyst, leaves the snail, and swims away in search of the definitive host.

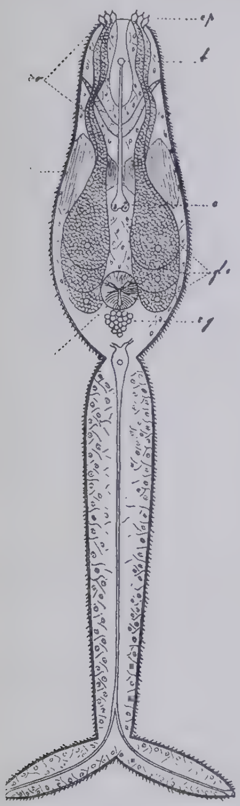


FIG. 112.—Cercaria of *Schistosoma hæmatobium.* *vo.*, oral sucker; *n.*, nervous system; *vp.*, ventral sucker; *b.*, digestive system; *gl.c.*, cephalic glands; *c.g.*, germ cells. (After Bettencourt and Borges)

The cercaria of the schistosomes may develop in a number of fresh-water snails as shown in Table V.

The cercariæ are very small (about 500 μ in length) and are covered with backward pointing spines. The oral and ventral suckers have well developed musculature. Prominent so-called "cephalic glands" occupy the posterior half of the body. These are unicellular with large nuclei. It seems probable that these glands produce secretions which dissolve the tissues of the host, or may also serve to neutralize the toxic secretions which the host produces in its attempt to combat the entrance of the cercaria. Their ducts pass forward in two groups and enter the oral sucker. The duct openings are capped with hollow, piercing, spinose tubes whose function is to drill microscopic holes in the skin of the final host at the time of invasion so that the proteolytic secretions of the cephalic glands may the more readily digest away the host tissue.

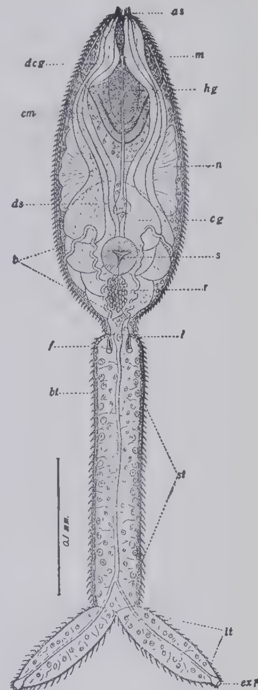


FIG. 113.—Cercaria of *Schistosoma japonicum,* ventral view; *as,* anterior spines; *b,* excretory bladder; *bt,* excretory bladder of tail; *cg,* cephalic glands; *cm,* circular muscles; *dcg,* ducts of cephalic glands; *ds,* digestive system; *exp,* excretory pore; *f,* flame cell; *hg,* head gland; *i,* island in excretory bladder; *lt,* lobe of tail; *m,* mouth; *n,* nervous system; *st,* stem of tail; *s,* ventral sucker. (After Cort)

The digestive system is in a very rudimentary stage of development. The mouth is situated on the ventral surface a little back of the anterior tip. The esophagus extends posteriorly to about the level of the cephalic gland where it widens into a heart-shaped structure which represents the beginning of the bifurcation of the intestinal ceca. It is non-functional during the free-swimming period of the cercaria.

The only trace of the complicated reproductive system of the adult is a small mass of nuclei on the ventral side back of the acetabulum. Since sexual dimorphism is manifest very early in the development of the final host it is evident that there must be a sexual differentiation in the cercariæ, yet no one has actually observed this condition.

6. METHODS OF HUMAN INFECTION

Man acquires schistosomiasis either by drinking water containing cercariæ, or by bathing in infected streams or canals, working in rice cultivation or in following other similar occupations in which the cercariæ are given an opportunity to penetrate the exposed skin. Most cases of infection are by the direct penetration of the host's skin by the cercariæ, and the usual entrance is by way of the hair follicles. Entering the lymphatics or blood vessels the young schistosomes proceed to the liver and in from six to eight weeks attain sexual maturity. After egg production has started the adult flukes make their way down into the mesenteric branches of the portal vein.

A number of prenatal infections with *Schistosoma japonicum* have been observed in both man and lower animals. Narabayashi (1914-1916) found ova of this parasite in the feces of three out of twenty-two new-born babies. The mothers of these children all gave a history of having worked in the rice fields during their pregnancy. Infections arising in this manner have been observed a number of times in experimental animals. The young parasites are carried to the placenta in the blood stream, migrate through the thin membrane separating the circulation of the mother from that of the fetus, and are then carried to the fetus by its own blood vessels.

7. PATHOLOGY

The differences in the diseases caused by the three species of schistosomes in man are due chiefly to differences in the place of

giving off of the eggs. It will be recalled that *S. hæmatobium* prefers the veins of the urinary bladder whereas *S. mansoni* and *S. japonicum* are more restricted to the veins of the large intestine. The pathological changes brought about by these parasites depend very much on the number of worms harbored and the duration of the

FIG. 114.—Cross-section of male and female *Schistosoma hæmatobium* situated in a distended vein at the juncture of the submucosa and muscular wall of the bladder. This vessel is evidently occluded by the inflammation which the worms' presence has excited. The intestinal ceca of the female are distended with deeply stained material to the right of which is the ovary. (Photograph by Tyzzer)

infection. Early in the disease caused by *Schistosoma hæmatobium* the bladder may show either diffuse reddening or hyperemia. Small vesicular or papular elevations are found on the surface of the mucosa, which give it a sandy appearance. Upon section, these elevations are found to contain ova. The eggs are principally deposited in the submucosa and tend to appear in patches. Worms in copula also occur in the veins of this layer. Ulceration may occur and the

inflammatory change produced by the egg may give rise to hypertrophy and hyperplasia of the mucosa resulting in papillomata which bleed readily. Occasionally the inflammation extends to the ureter and results in obstruction due to the thickening of its walls. In other instances the seminal vesicle and the prostate of the male, and the urethra and vagina of the female may also be involved. In case of infections with *S. mansoni* a similar type of reaction takes place in the rectum (Figure 114).

In cases of schistosomiasis japonicum the liver and spleen become greatly enlarged. The liver is cirrhotic and contains many eggs which may be present in the scar tissue or surrounded by foreign-body giant cells. Besides the lesions produced by the local deposition of ova there is also a general thickening of the walls of the portal veins; this also has been observed in Egyptian cases and is attributed by Fairley (1920) to toxins secreted by the adult worms. The spleen, however, seldom contains ova and the enlargement of that organ is probably due to absorption of toxins or a portal stasis. Hematin is prominent in both the liver and spleen. Ova are found in large numbers in the mucosa and submucosa of the intestine, particularly the lower part, where they give rise to ulcers and polypoid masses. The bladder is not affected. Occasionally ova of the schistosomes have been found in the brain.

8. SYMPTOMS

When the cercariæ of the schistosomes penetrate the skin of man, a definite skin eruption follows which is known as "Kabure" in Japan. The lesions more or less resemble flea bites and appear two or three days after exposure to the cercariæ. Itching precedes the appearance of the lesion. The lesions become smaller after four or five days and disappear entirely in about a week's time. The clinical course of schistosomiasis japonica has been divided into three stages by Faust and Meleney (1924): (1) the stage of invasion and maturation of the parasite, in which the disease is characterized by toxic symptoms, malaise, cough, giant urticaria with edema, intense eosinophilia and abdominal symptoms; (2) the stage of deposition and extrusion of eggs, which is characterized by blood and mucus in the feces, with or without diarrhea and by the continuation of fever and malaise, associated with epigastric pain; ova of the parasite are almost constantly found at this time in the feces; the liver and spleen become enlarged and a progressive anemia develops; the eosinophilia is varied in degree; (3) the stage of tissue reaction and repair in which symptoms of cirrhosis of the liver and portal obstruction

appear. Extreme weakness and emaciation follow, and finally death. Frequent superimposed infections often combine this picture with that of the second stage.

Hematuria is the most characteristic symptom in infections with *Schistosoma hæmatobium.* Symptoms of catarrh of the bladder appear in severe forms with occurrence of calculus and ureteral obstruction; and in cases of secondary septic infection, a septic cystitis often supervenes. Ova have been found in the brain and spinal cord to which have been attributed epileptic and paralytic symptoms. In the lungs the ova may give rise to a form of interstitial pneumonia, especially when occurring in large numbers. Dysenteric symptoms may occur with rectal involvement.

In early infections with *Schistosoma mansoni* the symptoms resemble those of Japanese schistosomiasis. Polypoid growths, similar to those in the bladder, are met with in the mucosa of the rectum. Pneumonia, from egg deposition in the lungs, is an occasional complication.

The condition known as Egyptian splenomegaly, which is a common disease in Egypt and Northern Nyasaland, is believed to be caused by *Schistosoma mansoni.*

9. PROPHYLAXIS

The spread of schistosomiasis is largely due to neglect of sanitation. In Japan and China, however, human feces are absolutely necessary for the successful fertilization of arable lands. In Egypt all of the arable land lies in the immediate vicinity of the Nile River, or in tracts of land well irrigated from the Nile. Human excreta are not used extensively as crop fertilizer, but are directly deposited in the canals through the religious customs of the people. The majority of the inhabitants are Mohammedans whose religion orders rigid cleansing with water of the urethral and anal openings after defecation or urination. In order that the required ablutions may be performed with ease, the villagers urinate and defecate into or near the stream. The ova from infected individuals are thus either deposited directly into the natural environment of the molluscan hosts or are washed into the canal with water used in cleansing the body.

In Japan prophylactic measures against schistosomiasis have been concentrated on the eradication of the snail host, *Blanfordia nosophora.* Lime in a concentration of 0.1 per cent has been found effective not only in killing the snail host, but in destroying the cercariæ as well. It is spread thickly on the banks and in slowly

running water. Chlorinated lime and copper sulphate are also efficacious against the snails but have been found detrimental to crops. Irrigation is not an effective measure as the snails of this genus are operculate and can withstand great intervals of drying. Reservoir hosts are eliminated as far as possible from the endemic areas and the possession of dogs and cats is discouraged. Oxen are replaced by horses, as the horse appears to acquire immunity against the disease.

Adequate protection of the skin is also advised for the farmer who is forced to work in the flooded rice fields or follow other occupations which may expose him to the infection. This measure, however, has not been found practical, for it involves the purchase of clothing to be worn which is contrary to both custom and comfort.

Extensive, specific treatment against schistosomiasis is now maintained throughout Egypt in out-patient clinics by the Egyptian Government. These clinics are usually crowded each day with patients to receive free treatment and much suffering is thereby temporarily relieved. However, the drugs do not protect the individual from reinfection, and it is only a short time before reinfection brings on his former condition and he applies for another course of treatment. Without definite measures against the free stages of the parasites and the intermediate host, the value of treatment alone is therefore questionable.

Warnings should be made against drinking or bathing in canals or rivers of endemic areas. Only boiled water or water treated with sulphate-of-soda tablets should be used for drinking and water boiled or treated with lysol, creolin or cresol in solutions of 1 : 10,000 for bathing. Leiper (1916-1918) has shown that the cercariæ of *S. mansoni* and *S. hæmatobium* live in water only about forty-eight hours after the escape from the snail unless the mammalian host is successfully entered but that the snail once infected may remain so for several months. Stored water, free from snails, would then be safe for bathing, as far as any danger from schistosome infections is concerned, but it may still be dangerous from other pollutions unless chemically disinfected or boiled. Chlorine in the strength of 1 : 1,000,000 appears to have no effect on the cercariæ.

Periodic drying of the canals and irrigation ditches would be effective against the snail hosts of *S. mansoni* and *S. hæmatobium* as they are non-operculate species and are killed by desiccation (Khalil, 1922).

So far as we know *S. mansoni* occurs only in man and *S. hæmatobium* has been found but once in a lower mammal, the sooty

monkey, therefore there is no serious reservoir of infection with these two species.

10. TREATMENT

Preparations of antimony, usually in the form of sodium or potassium antimony tartrate, are successfully used in treating schistosomiasis. Sodium antimony tartrate is generally used in Egypt. The course of treatment for an adult consists of twelve injections given intravenously on alternate days or three times a week over a period of four weeks, administered as follows:

	Grains of Antimony Sodium Tartrate		
	1st time	*2nd time*	*3rd time*
First week.....	1	1½	2
Second week...	2	2	2
Third week....	2	2	2
Fourth week...	2	2	2

Women and children are given smaller doses, the full dose being 1¼ to 1½ grains.

Emetine is used for children when it is unwise to attempt an intravenous injection, and is given subcutaneously.

Medical treatment kills the parasites in the tissues but does not remove the effects of their presence. Therefore it is necessary in advanced cases to excise the papillomatous growths which obstruct the intestinal lumen, and similar growths may be removed from the bladder or from other structures similarly effected.

CHAPTER XXII

CLASS CESTODA

I. *General Characteristics of the Class*

The CESTODA are all endoparasitic flatworms and are commonly known as "tapeworms." Almost without exception the adult stage is found only in the alimentary tract of vertebrates while the larval forms may inhabit various tissues of both vertebrates and invertebrates (ARTHROPODA). A few primitive cestodes closely resemble the trematodes in that they have a small, simple body but differ from the trematodes in the absence of a digestive system, which is a common characteristic of all tapeworms. The majority of cestodes, especially those occurring in mammals, however, are well differentiated from the trematodes. They are all more or less like a band or ribbon which is divided by cross-marking into a series of segments or proglottids. The adult worms frequently attain a length of several meters, and may consist of several thousand proglottids. In no stage of development of the cestodes is there any trace of a digestive system. Nutriment is absorbed through the entire surface of the body.

I. EXTERNAL ANATOMY

The adult tapeworm (Figures 115, 123, 132) is typically composed of three fairly distinct regions: (1) the scolex, (2) the neck and (3) the strobila, or the chain of proglottids. The scolex is more or less enlarged, globular or oval in outline and is structurally adapted for adhesion or fixation to the intestinal wall. It is commonly supplied with four cup-shaped suckers (acetabula) placed crosswise at its circumference (Figures 130, 133). In certain species of tapeworms the scolex carries long, double or quadruple groove-like suckers which are known as bothria (Figure 123, B). This organ of attachment may also be supplied with hooklets which, when present, are usually numerous and arranged in one or more circular rows around a single protractile organ, the rostellum, located at the tip of the scolex. The scolex is said to be armed or unarmed according to

either the presence or absence of these hooklets. Whether the scolex represents the head or the posterior extremity of the worm is a question which has been the subject of much discussion among zoölogists. Many investigators maintain that it is at the anterior extremity because here the chief nerve centers are located. Others claim that the scolex is at the posterior end. In the larval development of certain forms the scolex is at the posterior extremity of the larva, and it is therefore held that the scolex must represent the morphological posterior extremity of the adult.

Immediately following the scolex there is usually a slight constriction which is termed the neck. This portion connects the scolex with the segments and is itself non-segmented. It is the budding zone, composed largely of actively growing germinative tissue, from which new segments or proglottids are formed. The proglottids nearest the neck are the youngest and are quite indistinct and undifferentiated. But as one proceeds posteriorly the proglottids gradually become larger and broader; there also takes place a gradual and progressive development of the organs within each proglottid (organogenesis).

FIG. 115—*Tænia hydatigena.* Showing the general characteristics of a tapeworm, S. Scolex. (Photograph by Ransom)

The cestodes, as in the trematodes, are hermaphroditic, each proglottid containing all the organs of both sexes, and in some instances two sets occur in each. The reproductive organs are about the only structures remaining in the proglottid and, since there is no connection of these organs in one proglottid with those of the preceding or succeeding proglottids, each proglottid or segment may be considered an individual, and the strobila as a group of individuals which have remained united to form a colony as a result of incomplete separation following asexual reproduction.

The segments near the neck contain only the rudiments of reproductive organs but as one proceeds backward the gradual development of these organs can be observed. The male organs are the first formed. Toward the center of the strobila the sexual organs of both sexes are well differentiated and fully developed (Figure 116).

These segments are termed "mature" and the various parts of the reproductive systems are similar in character and interrelation to those of the trematodes. In many species, especially those of the CYCLOPHYLLIDEA, the uterus becomes crowded with ova toward the terminal portion of the strobila and it largely replaces the other reproductive organs which gradually shrink and may remain only as vestiges. These are known as "gravid" proglottids (Figure 134). The

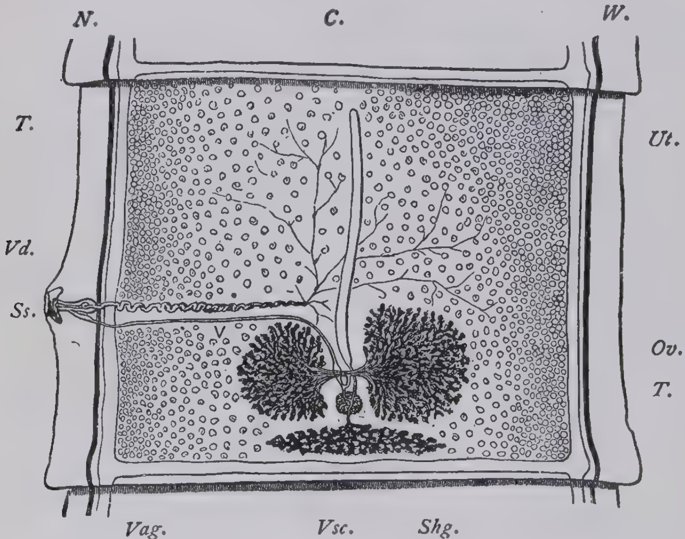


FIG. 116.—Mature proglottid of *Tænia saginata* showing genitalia, *C.*, transverse excretory canal; *N.*, lateral longitudinal nerve; *W.*, longitudinal excretory canal; *T.*, testes scattered throughout the proglottid; *Ut.*, opposite the ventral uterine stem (a closed sac); *Ss.*, genital pore leading into the genital sinus; above the cirrus and coiled vas deferens (*Vd.*), below the vagina (*Vag.*), bearing near its termination a dilatation, the seminal receptacle; *Vsc.*, the triangular vitellarium, and above it (*Shg.*) the shell gland; leading from this to the uterus is seen the short uterine canal, on either side of this the two lobes of the ovary (*Ov.*) 10/1. (From Fantham, Stephens, and Theobald, *Animal Parasites of Man*)

gravid segments, either singly or in groups, finally become separated from the chain, and are carried to the exterior in the host's feces. The PSEUDOPHYLLIDEA, however, do not have ripe segments in the same sense as other cestodes. These cestodes have a uterine pore and continually give off eggs and the uterus does not become branched due to the overcrowding of eggs. In this respect the PSEUDOPHYLLIDEA closely resemble the trematodes.

The proglottids usually show at least one prominent, external opening, the pore of the common genital atrium into which the

cirrus and the vagina open. This opening is commonly located on one lateral border or on a surface of the proglottid. In PSEUDOPHYLLIDEA there is a second female opening, the uterine pore which has just been mentioned. Its position may be used to determine the ventral surface of the worm. When the uterine pore is absent, it is customary to call the surface which is nearest the ovary ventral.

Morphologically, the cestodes closely resemble the trematodes. The body is covered with a homogeneous, elastic layer, the cuticula, which for the most part is devoid of spines or other appendages, and which is produced by special cells situated in the parenchyma. The

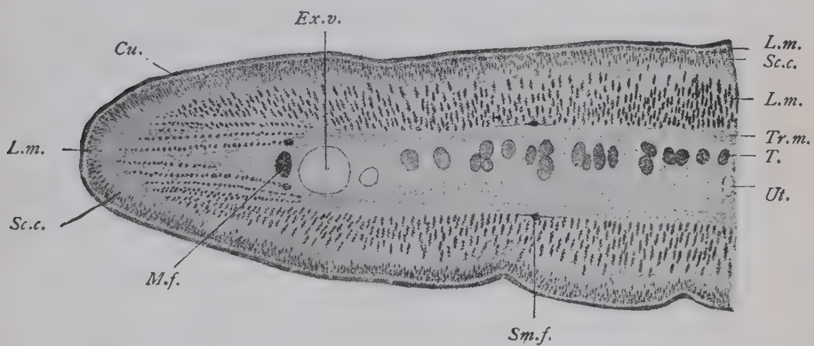


FIG. 117.—Half a transverse section through a proglottid of *Tænia crassicollis*. *Cu.*, cuticula; *Ex.v.*, external excretory vessel, to the right of which there is a smaller internal one; *T.*, testicular vesicle; *L.m.*, longitudinal muscles (outer and inner); *M.f.*, lateral nerve with two accessory nerves; *Sc.c.*, subcuticular matrix cells; *Sm.f.*, submedian nerve; *Tr.m.*, transverse muscle; *Ut.*, the uterus; and the middle of the entire transverse section. 44/1. (From Fantham, Stephens, and Theobald, *Animal Parasites of Man*)

parenchyma, as in TREMATODA, fills out all the spaces between the different organs and muscles (Figure 117).

Embedded in the parenchyma are located light, refracting, concentrically striated structures, spherical or broadly elliptical in outline which are termed calcareous corpuscles, so named because they contain carbonate of lime. They may vary from 3 μ to 30 μ according to the species and are chiefly located in the cortical layer.

2. MUSCULAR SYSTEM

The muscular system of the proglottids is highly developed and is composed of circular, longitudinal, transverse and dorsoventral fibers. A single layer of circular muscles (subcuticular muscles) is followed by a thin sheet of two sets of longitudinal muscles, between

which are the subcuticular matrix cells. The inner layer of longitudinal muscles extends to the transverse fibers. The transverse fibers run from one side of the proglottid to the other and reach the cuticula. These occur in two layers and thus divide the parenchyma into two parts. That portion of the proglottid lying enclosed by these fibers is termed the medullary layer and contains all the organs except the principal nerve cords and the excretory tubules. The portion outside the transversal muscle fibers is termed the cortical layer. Dorsoventral fibers extend singly from one surface to the other; these serve to flatten the body.

3. NERVOUS SYSTEM

The nervous system commences in the scolex where several nerve bundles are connected by commissures, and from a rostellar ring which is generally referred to as the central part of the entire nervous system. Longitudinal nerve fibers run through the length of the strobila; those at the lateral border are usually the largest.

4. EXCRETORY SYSTEM

The excretory system of the cestodes is fundamentally the same as that described for the trematodes. Typically it consists of two pairs of longitudinal canals which extend along the lateral borders of the strobila, parallel to the longitudinal nerve trunks. Of these the inner pair is less well developed than the outer pair and may be missing in the older proglottids. The longitudinal canals are commonly connected by a transverse canal which crosses the proglottid close to its posterior border. These main canals receive smaller canals, the branches or collecting tubules of which ramify through the parenchyma and terminate in a flame cell. When the first-formed proglottid has been cast off the longitudinal canals discharge separately; however, if the last segment represents the original proglottid, the canals unite to discharge from a single pore.

5. REPRODUCTIVE SYSTEMS

The arrangement of the reproductive organs varies greatly in the different genera. As an example the genus *Tænia* is illustrated (Figures 116 and 118).

The male organs consist of from one to several hundred testes, according to the species, embedded within the parenchyma near the

dorsal surface. From each testis minute ducts, the vasa efferentia, are given off which finally unite at about the middle of the proglottid and form the vas deferens. The vas deferens, after a more or less convoluted course, leads into the cirrus which is usually enclosed in an elongated cirrus-sac or pouch. The cirrus opens into a cup-shaped cavity, the common genital atrium, the raised border of which stands out more or less prominently above the edge of the segment and forms the genital papilla. The vagina also opens into the common genital atrium. The genital pore is located either on the lateral margin of the proglottid or on the ventral surface, according to the species. Tapeworms which have two sets of reproductive organs in each proglottid have two genital pores.

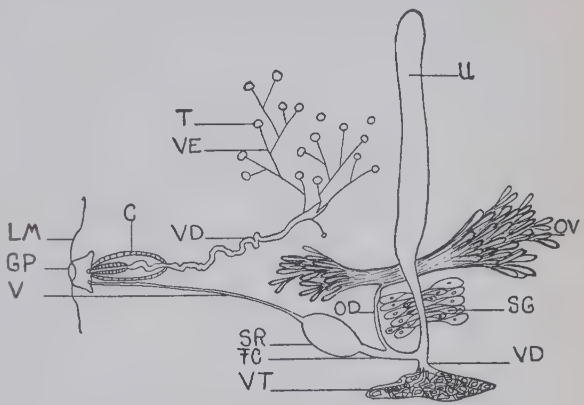


FIG. 118.—Diagram of the genitalia of a tænioid cestode. C, cirrus sac; FC, fertilization canal; GP, common genital pore; LM, lateral margin of the proglottid; OD, oviduct; OV, ovary; SG, shell gland surrounding the oötype; SR, seminal receptacle; T, testes; U, uterus; V, vagina; VD, vas deferens; VE, vasa efferentia; VT, vitellaria.

The female genital opening, situated posterior to the male genital opening in the common genital atrium, leads into the vagina, a thin straight tube which passes parallel with the vas deferens to the middle of the proglottid where it bends downward into a dilated portion which serves as a seminal receptacle. Immediately beyond this dilatation the vagina connects with the common oviduct and then continues as the fertilization canal to the oötype, where it is joined with the vitelline duct. The ovary is composed of a number of tubular follicles and is usually bilobed. It is situated posteriorly in the proglottid. The vitelline gland is a single, compact body follicular in character and lies posterior to the ovary. Its duct is short. The so-called "shell gland" which surrounds the oötype has an almost circular outline and is made up of numerous unicellular glands which open separately into the fertilization canal at the place of union with the uterus and vitelline duct. The uterus at first appears as a straight, blind tube of con-

siderable size and runs forward almost to the anterior margin of the proglottid. In older segments the uterus shows very complex branching or pouches filled with eggs and these branches occupy practically the entire volume of the proglottid. While still in the proglottid, the eggs are carried to the exterior with the feces and are set free later upon the disintegration of the segment.

In PSEUDOPHYLLIDEA the uterus consists of a single tube which opens on the ventral surface of the proglottid through the uterine pore. The eggs are continually discharged from the worm as in the trematodes, and are therefore found free in the host's feces.

6. REPRODUCTION

As each proglottid possesses its own genital apparatus, it is probable that autofecundation most frequently occurs, although copulation between the segments of different worms and between different segments of the same worm has been observed. The spermatozoa in either mode pass down the vagina and are temporarily stored in the seminal receptacle. When the eggs and spermatozoa meet, fertilization occurs. The fertilized eggs and yolk material from the vitelline glands pass into the oötype which is surrounded by the so-called shell gland, and here the shells are formed about the eggs which are then passed on into the uterus.

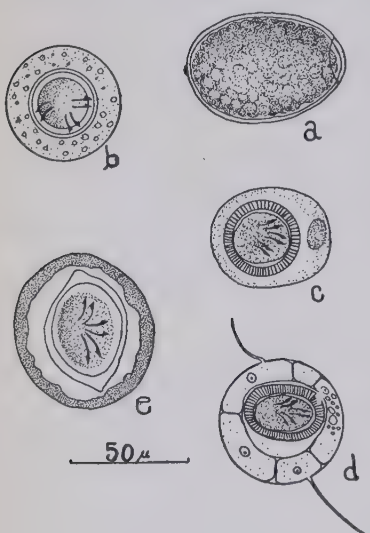


FIG. 119.—Types of cestode eggs. a., *Diphyllobothrium latum;* b., *Dipylidium caninum;* c., *Tænia solium;* d., *Tænia saginata;* (The thin, delicate outer membranes of the eggs of *Tænia* are usually absent, but may be seen on some of the eggs taken directly from the uterus.) e., *Hymenolepsis diminuta.* (Original)

Two distinctly different types of cestode eggs are produced. In genera that possess a uterine pore the mature eggs are strikingly similar to trematode eggs. They are oval in outline, yellow or brownish in color, and the shell, which is operculate, contains the fertilized ovum and yolk cells (Figure 119a). In genera with no uterine pore, the egg-shell is a very thin, delicate structure, and has no operculum and there is but a scanty amount of yolk material. As the embryo within these

eggs develops various membranes are formed immediately around it, and constitute what is known as the embryonal shell or embryophore. In TÆNIDÆ the egg shell proper is, as a rule, soft and colorless and soon disappears after the formation of the embryophore. As the embryophore is rather thick, brown in color, and composed of numerous calcified rods (Figure 119, c and d) and is the only structure usually seen surrounding the embryo it is often erroneously called the egg-shell. In HYMENOLEPIDIDÆ the embryophore is thin and colorless like the egg-shell, which is retained (Figure 119, e). In DIPHYLLOBOTHRIIDÆ the embryophore bears long cilia (Figure 125, b and c) by the aid of which the embryo swims about after its escape from the egg-shell.

FIG. 120.—Cysticercoid of *Dipylidium caninum*. The tail is a solid structure and bears on it the embryonal spines. The bladder, which was only slightly developed, has disappeared, and the fore-part of the body bearing the rostellum is now seen invaginated into the hind portion. The hooklets are shown in front of the excretory system. At a later stage the tail drops off and the scolex evaginates. Enlarged. (From Fantham, Stephens, and Theobald, *Animal Parasites of Man*. After Grassi and Rovelli)

The embryonal development of most tapeworms takes place while the eggs are in the uterus although in PSEUDOPHYLLIDEA cleavage starts only after the eggs have left the host. The embryo when completely formed bears six minute hooks and is termed the onchosphere. Further development of the onchosphere only takes place when it is ingested by a suitable intermediate host. Upon entering the alimentary tract of this host, the onchosphere escapes from the embryophore and, with the aid of its hooks, actively bores its way out of the alimentary canal into the body cavity or vascular spaces. It may remain there and undergo further development or, by active or passive migration, reach a preferred tissue where it encysts and passes into a larval stage common to all tapeworms but which varies greatly in structure according to the species. Among the lower cestodes (PSEUDOPHYLLIDEA) this larva is called a procercoid. It develops directly from the onchosphere. It is a small, spindle-like, solid body with a cephalic invagination and a spherical appendage at the opposite end which is provided with six hooks. The procercoid gives rise in a second intermediate host to a larva known as a plerocercoid, which is also a solid body but more elongated and worm-like than the procercoid and has no hooked appendage. Among the higher cestodes (CYCLOPHYLLIDEA) are larval forms with bladders from which the scolices arise. Two types of these larvæ are generally recognized, (1) cysticercoid (Figures 120-153) which

has only a rudimentary bladder and has the anterior portion drawn into the posterior region and may be provided with a long or stumpy tail; and (2) cysticercus, or true bladder worm. Of the true bladder worms, the following types are known to occur, (a) cysticercus proper which consists of a bladder, usually small, in which only a single scolex develops (Figures 121-122); (b) cœnurus, a large bladder in which a great number of scolices arise directly from the germinative membrane, each invagination containing but a single scolex (Figure 146); and (c) the echinococcus, or hydatid, which produces daughter and granddaughter cysts in which brood capsules develop which give rise to numerous scolices from a germinative membrane (Figures 139-140). These larval forms are the infective stages for the definitive host and each scolex is capable of developing into an adult worm when swallowed by a suitable host.

FIG. 121.—*Cysticercus cellulosæ*. The cysticerci have been extracted from their cysts. Natural size. (Photograph by Ransom)

These larval stages of tapeworms, the cysticerci, were considered for many years as distinct species of animals and were included among the other intestinal worms. Zeder in 1800 established a special group, *Cystici* Rud., 1808, for them. It was not until 1851, however, when Küchemmeister, by feeding experiments, demonstrated that they were definite stages in the development of certain tapeworms, that their exact position was known.

FIG. 122.—Median section through a cysticercus, with developed scolex at the bottom of the invagination. (After Leuckart)

As an illustration of the development of a cestode, the life-cycle of *Tænia pisiformis*, a common tapeworm of dogs, will be outlined. The adult worm normally occurs in the intestine of the dog but may also occasionally be found in cats. The gravid segments become detached from the end of the strobila and are carried to the exterior in the dog's feces. These detached proglottids have independent

powers of movement and usually show considerable activity when first passed. The proglottid may soon disintegrate but the onchospheres which are surrounded by the protective membrane, the embryophore, may remain viable for a considerable period in the grass or among other vegetation where they may be taken into the alimentary tract of a suitable intermediate host, an herbivore, along with its food. The common cottontail, *Sylvilagus floridanus,* usually serves as the intermediate host of *T. pisiformis.* In the stomach of the rabbit the onchosphere is freed by the action of the digestive juices upon the embryophore and, with the aid of its hooks, the onchosphere penetrates the intestinal wall and enters the blood stream.

It is carried in the blood stream to the liver where it soon loses its hooks and begins development as a bladder worm, commonly known as *Cysticercus pisiformis.* Development of the cysticercus is not completed in the liver but in about thirty days after the ingestion of the onchospheres the larva becomes very active and migrates from the surface of the liver. It falls into the abdominal cavity where it remains free for a time, but ultimately becomes attached by an adventitious cyst to the mesenteries and becomes a fully formed cysticercus. Here it lies without going further in its development unless the infected rabbit is eaten by another animal (dog or cat) which is suitable as a host, in which event the living cysticercus is liberated from its confining cyst by the digestive action of the intestinal juices and the inturned scolex becomes everted and secures attachment to the lining of the intestinal wall. The scolex is not affected by the digestive processes but the cyst proper soon disintegrates leaving only the scolex and neck which, through growth, produce the entire strobila.

All of the tapeworms, as well as other helminths inhabiting the intestinal tract, show a remarkable ability to resist the proteolytic and dissolving action of the digestive juices. Diastre and Stassano (1903) have demonstrated that *Tænia pisiformis* and the nematode *Ascaris* sp. secrete during life an antikinase which neutralizes the pancreatic juices. After death, however, these worms become quickly disintegrated by the digestive processes of the host.

7. LONGEVITY

Many species of tapeworms are known to be but short-lived within the host, while others, under favorable conditions, may live for a very long period. Leuckart (1886) states that one of his Rus-

sian students harbored two tapeworms, *Tænia saginata*, for more than five years and mentions other instances where this parasite lasted from twenty to thirty-five years. Riley (1919) has recorded two infections with *Diphyllobothrium latum* of unusually long standing. The first infection was in a Russian Jew who had left Russia some five years previously and had not been exposed to infection since arriving in the United States. The second, a Swedish woman, was definitely known to carry the infection for thirteen years and evidence indicated that the infection had lasted for twenty-nine years.

8. INJURY TO HOSTS

The degree of injury caused by adult cestodes to their hosts varies considerably with the species involved and the number present.

They are usually more or less inactive animals and for the most part occur only in the small intestines. To what extent the host suffers from loss of food which is absorbed by the worm depends largely on the size of the worm, the number of worms present and the physical condition of the host. Surely the amount of nutriment required by a large tapeworm for growth and sexual development would be a considerable loss to the host, especially if the host were young, undernourished, or otherwise weakened. Tapeworms may also bring about a reduction or complete occlusion of the intestinal lumen. They also produce changes in the intestinal mucous membrane at the place of their attachment by the suckers and hooks of the scolex. The scolices of some species of tapeworms penetrate deeply into the submucosa and at times may be embedded even in the muscles of the intestinal walls. The wounds thus caused by the penetration of the scolex into the intestinal wall allow the entrance of bacteria which may result in destructive ulceration. Toxins liberated by the tapeworms give rise to nervous symptoms and in certain cases cause extreme anemia. Patients may never complain of symptoms if they are ignorant of the infection, but if they know they harbor these parasites almost any kind of symptoms may be educed. The most common complaints are loss of appetite or excessive hunger, nausea, abdominal pains, vertigo, pruritus, cardiac palpitation, anemia, emaciation, and general weakness, all of which usually rapidly disappear after the removal of the worms.

The cystic stages of tapeworms usually give rise to more serious conditions, especially in the case of *Echinococcus* which produces hydatids in the liver and other organs, causing symptoms characterisic of a slowly growing tumor. Bladder worms of certain

tapeworms have an important bearing upon the sanitary control of meat food products and their presence in the muscles or other parts of the body of cattle, hogs and sheep constitutes the disease known as "measles." The bladder worms of *T. solium* and *T. saginata* have been reported from man. Those of *T. saginata* occur less frequently though in man than do those of *T. solium*. When they are situated in the skin or muscles they are of but slight importance. However, when they occur in the eye or brain they give rise to serious disorders and only by surgery can these, as well as hydatids, be removed.

9. ANTHELMINTIC MEDICATION

Treatment for tapeworms, as well as for all helminths, is contraindicated in any debilitated condition. The debilitating condition first should be treated palliatively and the patient's general health brought up as far as possible before the anthelmintic is administered. As most effective drugs used to expel tapeworms are toxic to the host as well as to the parasite one should consider whether the presence of the parasite or the treatment constitutes the greater harm to the patient. Under no circumstances should anthelmintics be administered without the supervision of a physician.

Oleoresin of aspidium has long been known to have a selective action for tapeworms and is the drug most commonly employed in expelling these parasites from the host. Because of its marked toxic action it should not be given to young children. Magath and Brown (1927) report exceptional success with this drug when administered in the following manner:

> The patient should not have lunch or supper the day previous to treatment but black coffee or tea and water may be given freely. At 6 o'clock in the afternoon from 15 to 30 gm. magnesium sulphate is administered and again at 6 o'clock in the morning the same dose is administered again.
>
> No breakfast is given and after the bowels have moved, 30 c.c. of the following emulsion is administered: oleoresin of aspidium, 6 c.c. or gm.; powdered acacia, 8 gm.; distilled water sufficient to make 60 c.c. One hour later a second 30 c.c. of the emulsion is administered which is followed two hours later with 30 gm. of magnesium sulphate. Two hours after this a large soapsuds enema is given. The patient passes the stool into a container and it is examined for the tapeworm together with the stool which was passed before the administration of the anthelmintic.
>
> Providing the patient has been properly prepared, the stool will consist of practically nothing but water, some bits of digested food and the worm. The entire stools are passed through a sieve (20 mesh) and the contents in the sieve washed by running warm tap water through it. The contents are emptied into a flat, enameled pan, about 25 x 30 cm. which

TABLE VI

DISTRIBUTION, INCIDENCE AND DIAGNOSIS OF THE COMMONER AND MORE IMPORTANT CESTODES

Order	*Scientific Name*	*Organ Inhabited*		*Geographical Distribution*	*Incidence*	*Diagnosis*
		Adult	*Larval Stage*			
PSEUDOPHYLLIDEA	*Diphyllobothrium latum*	Small intestine of man, dog, cat, fox	Procercoid in body cavity of copepods—plerocercoid in musculature and viscera of fresh-water fish	World-wide, including Europe, Africa, North America and Japan	Frequent in certain localities	Eggs in feces
	Diphyllobothrium mansoni	Small intestine of dogs and other carnivores	Procercoid in body cavity of copepods—plerocercoid in musculature and subcutaneous tissue of frog, snake and man	Japan, China, Africa, Australia, British Guiana and United States	Adult a frequent parasite of dogs, plerocercoid in man accidental and very rare	Characteristic plerocercoids in subcutaneous tissues
	Diplogonoporus grandis	Small intestine of man	Unknown	Japan	Rare	Eggs and characteristic proglottids in feces
	Sparganum proliferum	Unknown	Subcutaneous tissue of man	Japan, China, United States	Rare	Characteristic plerocercoid in subcutaneous tissue
CYCLOPHYLLIDEA	*Davainea cesticillus*	Small intestine of fowl	Cysticercoid in lepidopterus or coleopterus insects	Cosmopolitan	Frequent	
	Davainea tetragona	Small intestine of fowl	Cysticercoid in snails of genus Helix	Cosmopolitan	Frequent	
	Dipylidium caninum	Small intestine of dog and cat	Cysticercoid in fleas and lice	Cosmopolitan	Frequent in dogs, incidental in man	Proglottids and onchospheres in feces
	Echinococcus granulosus	Small intestine of dog and carnivores	Hydatid in liver, brain, lung, etc., of man, pig, sheep, etc.	Cosmopolitan, but more especially in Iceland, Australia and Argentine	Frequent in certain countries	Serum reactions X-ray, clinical symptoms

TABLE OF DISTRIBUTION, INCIDENCE AND DIAGNOSIS OF THE MORE IMPORTANT CESTODES—(*Continued*)

CYCLOPHYLLIDEA—(*Continued*)	*Echinococcus multilocularis*	Small intestine of dog and carnivores	Hydatid in liver, lung, etc., of man, pig, sheep, etc.	Southern Bavaria, Switzerland, Russia, Siberia	Frequent in certain localities	Clinical symptoms—perhaps also by serum reactions
	Hymenolepis diminuta	Small intestine of rats and man	Cysticercoid in insects and fleas	Cosmopolitan	Frequent in rats, incidental in man	Onchospheres in feces
	Hymenolepis nana	Small intestine of man, rats, mouse	Cysticercoid in intestinal villus of host harboring adult	Cosmopolitan	Frequent in rats, fairly frequent in man, especially in children	Onchospheres in feces
	Moniezia expansa	Small intestine of sheep	Unknown	Cosmopolitan	Frequent in certain localities	
	Multiceps multiceps	Small intestine of dog	Cœnurus in central nervous system of sheep, accidentally in calves, horse and man	Cosmopolitan	Frequent in certain localities	
	Multiceps serialis	Small intestine of dog	Cœnurus in connective tissue of rabbits, hares and other rodents	Cosmopolitan	Frequent in certain localities	
	Tænia crassicollis	Small intestine of cat	Larva (Strobilocercus) in liver of rats	Cosmopolitan	Frequent	
	Tænia hydatigena	Small intestine of dog	Cysticercus in liver, viscera, abdominal cavity of sheep and cattle	Cosmopolitan	Frequent	
	Tænia ovis	Small intestine of dog	Cysticercus in musculature of sheep	Cosmopolitan	Frequent	
	Tænia pisiformis	Small intestine of dog and cat	Cysticercus in liver, mesenteries of rabbits	Cosmopolitan	Frequent	
	Tænia saginata	Small intestine of man	Cysticercus in musculature of cattle	Cosmopolitan	Fairly frequent in man	Characteristic proglottids in feces—rarely onchospheres in fresh feces
	Tænia solium	Small intestine of man	Cysticercus in musculature of hog	Cosmopolitan	Usually not frequent in man	Characteristic proglottids in feces—rarely onchospheres in fresh feces
	Thysanosoma actinioides	Small intestine of sheep	Unknown	Western United States	Frequent among range sheep	

has a black bottom, upon which the tapeworm is easily detected. The large enema serves to wash out the scolex which may otherwise be withheld in the rectum. Should the treatment prove unsuccessful in removing the tapeworm, a period of three weeks should intervene before a second administration of aspidium.

Pumpkin seeds are especially recommended for children. They are bland and not irritating but large amounts are necessary to be effective. About 60 gm. of the seeds are grounded into a paste and may be taken with cocoa, honey or spread on bread.

Kamala and pelletierine have also been used considerably as tæniafuges. Pelletierine is a mixture of alkaloids derived from the bark of the pomegranate tree. It is held to be effective but because of its toxic action its use in children is not desirable. Kamala is very mild and suitable for children but is not an effective tæniafuge for man. It has, however, been found satisfactory for removing tapeworms from sheep and poultry. Oil of chenopodium is more selective for round worms but has also been found effective against the dwarf tapeworm, *Hymenolepsis nana.* Hall and Schillinger (1924) report successful removal of tapeworms from dogs with arecoline hydrobromide.

II. *Classification*

Four orders are generally recognized under CESTODA, (1) PSEUDOPHYLLIDEA, (2) CYCLOPHYLLIDEA, (3) TETRAPHYLLIDEA, and (4) TRYPANORHYNCHA. Recently Southwell (1925) created a fifth order, the HETEROPHYLLIDEA. All of the cestodes of particular interest with respect to man and the higher vertebrates are included in the first two orders, the PSEUDOPHYLLIDEA and the CYCLOPHYLLIDEA. The following classification is largely after Southwell (1925).

Order 1. PSEUDOPHYLLIDEA Carus, 1863. CESTODA; scolex with two, rarely one, never four bothria. Uterine pore on the surface of the proglottid and the uterus in the form of rosette-shaped coils or of a large sacculate uterine cavity. Eggs operculated. Example, *Diphyllobothrium latum, Diplogonoporus grandis.*

Order 2. CYCLOPHYLLIDEA Braun, 1900, emended. CESTODA; scolex with four suckers, no uterine pore, proglottids set free after full maturity. Eggs not operculated. Examples, *Tænia saginata, Echinococcus granulosus, Dipylidium caninum.*

Order 3. TETRAPHYLLIDEA Braun, 1900, emended. CESTODA; scolex with four bothridia (lappet-like outgrowths from the head). A primary uterine pore, situated ventrally, is usually absent and a secondary uterine pore, or pores, due to atrophy of the ventral wall leading to dehiscence, occurs in some species in which true uterine pores are absent. Eggs not operculated. Parasitic in elasmobranchs.

Order 4. TRYPANORHYNCHA Diesing, 1863. CESTODA; scolex with four proboscides, each of which is armed with numerous spines. The adults are found in the spiral valve of elasmobranchs, the larval stages occur encysted in migratory fish.

Order 5. HETEROPHYLLIDEA Southwell, 1925. CESTODA; scolex very variable in appearance; it does not bear either four suckers, four bothridia, four proboscides or two bothria. Includes the genera *Echinobothrium* van Beneden, 1849; *Peltidocotyle* Diesing, 1850; *Amphoteromorphus* Diesing, 1850; *Discocephalum* Linton, 1890; and *Diagonobothrium* Shipley and Hornell, 1906.

The more important species of tapeworms of man and domesticated animals are listed in Table VI.

CHAPTER XXIII

THE ORDER PSEUDOPHYLLIDEA

The order PSEUDOPHYLLIDEA consists of but a single family, the DIPHYLLOBOTHRIIDÆ Luehe, 1910, which again is divided into two main groups or subfamilies, (1) LIGULINÆ Mont. and Crety, 1891, and (2) DIPHYLLOBOTHRIINÆ Luehe, 1910. The LIGULINÆ have a very short, and poorly developed scolex, no neck and the segmentation of the adults is often indistinct or entirely lacking. When present the divisions do not agree with the internal segmentation of the reproductive organs. Their larval stages are found in fishes, and the adults are largely parasites of birds. They are of but little, if any medical significance. One species, *Braunia jassyensis* N. Léon, 1908, has been found in Roumania. The ovary of this species is branched and has two rows of testes. Other *Ligulinæ* are said to have the testes arranged in a single row. The DIPHYLLOBOTHRIINÆ are, however, of considerable medical importance. They have a wide geographical distribution and the adults occur in the intestine of mammals, birds and reptiles. The broad or fish tapeworm of man, *Diphyllobothrium latum*, is of particular human significance.

I. *Diphyllobothrium latum* (Linn, 1758)

I. DESCRIPTION

Diphyllobothrium latum (Figure 123) is commonly referred to as the "broad tapeworm" or "fish tapeworm" of man. This parasite is one of the largest of the tapeworms and commonly attains a length of ten meters. The strobila may be composed of 3000 to 4000 proglottids. It is usually grayish yellow to brown in color. The scolex is more or less elongate, almond-shaped. It measures from 2 mm. to 3 mm. in length by 0.7 mm. to 1 mm. in breadth. The gravid segments usually measure from 2 mm. to 4 mm. in length by 10 mm. to 12 mm, even 20 mm. in breadth. The uterus is a long, coiled canal and appears as a dark, rosette-like object in the middle field of each of the older proglottids. It is a prominent structure,

even in freshly passed specimens, and its characteristic form is of diagnostic value. Gravid segments gradually lose their eggs so that those at the posterior extremity of the strobila may be entirely devoid

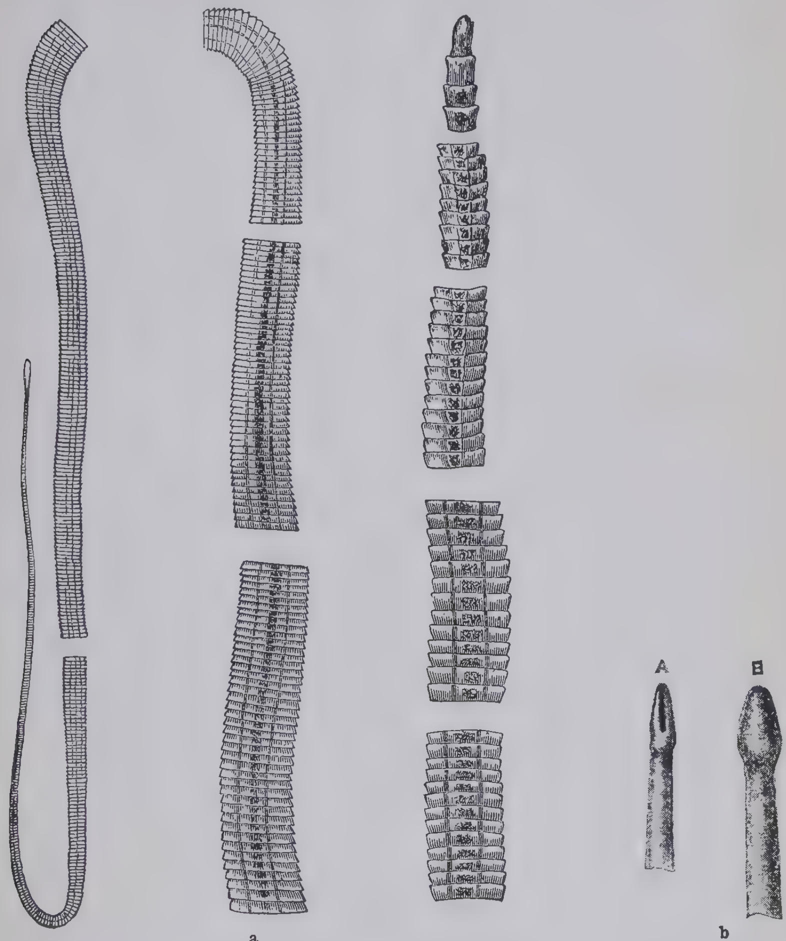


FIG. 123.—*Diphyllobothrium latum.* a, showing characteristics of the adult worm, natural size; b, scolices; B, from the flat side; A, from the margin. (After Leuckart)

of them. The gravid segments frequently break off from the parent worm in chains from a few to several feet in length and are passed to the exterior in the host's feces. Figure 124 shows graphically the arrangement of the parts of the reproductive system. The eggs,

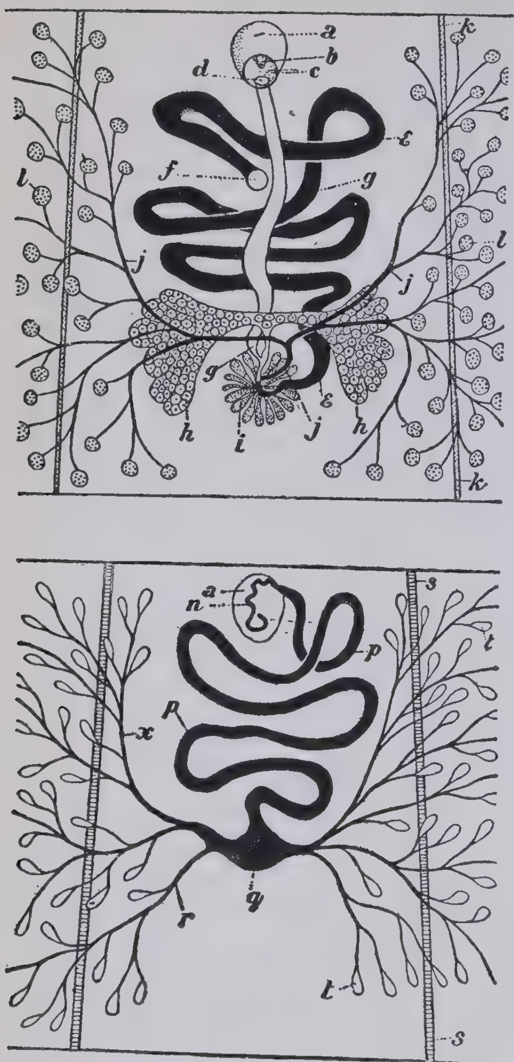


FIG. 124.—*Diphyllobothrium latum.* Upper figure: female genitalia, ventral view. Lower figure: male genitalia, dorsal view. The central portion only the proglottid is shown. *a*, cirrus sac; *b*, partly everted cirrus; *c*, genital atrium and pore; *d*, vaginal pore; *e*, uterus; *f*, uterine pore; *g*, vagina; *h*, ovary; *i*, shell gland; *j*, vitelline duct; *k*, lateral nerve; *l*, vitellarium; *n*, vas deferens (muscular portion); *p*, vas deferens; *q*, seminal vesicle; *r* and *x*, vasa efferentia; *s*, lateral excretory canal; *t*, testicular follicles. (From Fantham, Stephens, and Theobald, *Animal Parasites of Man.* After Benham, Somner, and Landois)

when present, occur in large numbers in the host's feces and are easily found in a simple smear preparation. They are large, 55 μ to 76 μ in length by 41 μ to 56 μ in breadth, brownish in color with a small, inconspicuous operculum at one end and a small knob or thickening of the shell at the other. The egg shell contains a slightly developed embryo surrounded by yolk cells.

2. FREQUENCY AND DISTRIBUTION

Diphyllobothrium latum in the adult stage is a parasite in the small intestine of man, dog, cat and fox. It has now become world-wide in distribution and is frequently found among inhabitants of districts surrounding fresh-water lakes where fresh-water fish forms a substantial part of the diet. In Europe there are three foci of infection: (1) the Baltic and North Sea littorals, spreading to the former Baltic

Province of Russia, now Esthonia, Latvia, and Lithuania, Northern Sweden, Denmark, Finland, Poland, Eastern Germany and Russia. The incidence is usually high in all of these countries, in Lapland it is said that nearly everyone is infected; (2) the region of the Alpine lakes, spreading to France, Piedmont, Bavaria and Italy; (3) the Danube basin, spreading to Austria, Roumania and Southern Russia. It is one of the most frequent cestodes of man in Turkestan and also occurs often in Japan. In Africa it is reported to occur around Lake Ngami, British Bechuanaland, and in Madagascar.

In the United States, *Diphyllobothrium latum* has been considered a rare parasite occurring only in emigrants from European endemic centers. However, a number of indigenous infections have been reported recently from Minnesota, Illinois, Indiana, Michigan and Massachusetts. It is therefore evident that the infection has now become established in this country and in certain parts of this country it may be the commonest of the large tapeworms of man.

3. LIFE-CYCLE

Diphyllobothrium latum requires two intermediate hosts for its development, the first, a fresh-water crustacean, Copepoda, and the second, a fresh-water fish.

The eggs are discharged in large numbers with the host's feces and, when these reach fresh water, a ciliated onchosphere develops within a period of a week or ten days if the temperature is favorable. This embryo, surrounded by its ciliated embryophore, escapes from its shell through the opercular opening and swims about freely for several days in the water. It is termed a coracidium. The coracidium soon dies unless it is ingested by one of a number of fresh-water copepods. *Cyclops strenuus* and *Diaptomus gracilis* in Europe (Janicki and Rosen, 1917), and *Cyclops brevispinosus, C. prasinus* and *Diaptomus oregonensis* in the United States (Essex, 1927) within which, however, it undergoes further development. Arriving in the intestine of the copepod the coracidium loses its cilia and penetrates the intestinal wall of its host with the aid of its hooks and comes to rest within the body cavity. Here it transforms itself into an elongated organism with cephalic evagination at one end and a circular caudal appendage carrying the embryonal hooks at the other. Its body is solid and is known as the procercoid. When fully grown, it measures about 0.5 mm. in length. No further development takes place unless the infected copepod is taken in as food by one of several species of fresh-water fish. When

this happens the procercoid becomes free in the intestine of the fish. It soon penetrates the intestinal wall of this host and finally encysts in the viscera and muscles after one week to thirty days. This larva is known as the plerocercoid. It is an oval or elongated, spindle-shaped, solid-bodied organism. In Europe the fish commonly found infected with plerocercoids are *Esox lucius, Lota vulgaris, Perca fluviatilis, Salmo umbla, Trutta vulgaris, T. lacustris, Coregonus lavaretus, C. albula, Thymallus vulgaris* and *Acerina cernua.* Recently Vergeer (1928) has found the plerocercoids of *D. latum* in wall-eyed pike, *Stizostidion vitreum,* sand pike, *S. canadense griseum,* pike, *Esox lucius* and burbot, *Lota maculosa* from Portage Lake, the Great Lakes Region, Michigan.

The plerocercoids have a chalky white appearance and are readily seen with the unaided eye. They vary from 1 mm. to 2 cms. in length and from 2 mm. to 3 mm. in diameter. They occur most frequently in the viscera of the fish but are also found encysted in the muscles. When these fish are eaten raw or in an insufficiently cooked condition by a susceptible host the plerocercoids are set free, the scolex becomes attached to the intestinal wall and quickly grows into the adult tapeworm at the rate of about thirty proglottids a day. Eggs may appear in the host's feces in as short a period as three weeks. Man and other hosts of the adult can be infected only by eating uncooked or improperly prepared infected fish. There is no danger of autoinfection with *D. latum* as in cases of certain other tapeworm infections, because of the necessary larval stages which require cold-blooded animals for their development. (See Figure 125.)

4. PATHOGENICITY

Diphyllobothrium latum, in addition to producing the more or less common gastric disorders and nervous symptoms, often gives rise to a severe and even fatal anemia with a blood picture indistinguishable from that of the true idiopathic pernicious anemia.

The cause of the primary type of anemia in *D. latum* infections has been the subject of much investigation and has been variously explained. In 1894 Schaumann made an elaborate study of the condition and suggested that the anemia was caused by the absorption of some toxic substance from the body of the worm. Schaumann and Tallquist (1898) fed dogs and rabbits with macerated pieces of the worm, fresh and also after tryptic digestion. Saline extracts were also injected subcutaneously into these animals, and an anemia was

observed in some of the dogs, but none in the rabbits. Schaumann and Tallquist demonstrated its hemolytic properties for the blood of the dog. Mesino and Calamida (1901) injected an extract of the worm into laboratory animals and obtained constant and characteristic symptoms such as tremor, depression of spirits, paresis of the lower extremities and somnolence. Control experiments showed that the symptom complex was not dependent on a simple proteid influence, but was caused by some substance in the tapeworm themselves. Faust and Tallquist (1907) observed that the worms obtained from patients having anemia generally show a great loss of substance and they advanced the theory that through death of the parasite in the intestinal tract of the host hemolytic substances were absorbed which brought about the characteristic action on the blood and bone marrow, and that the time and extent of the absorption would determine whether or not there is an anemia, the anemia developing only when there is a relative insufficiency of bone marrow. The resemblance of the blood

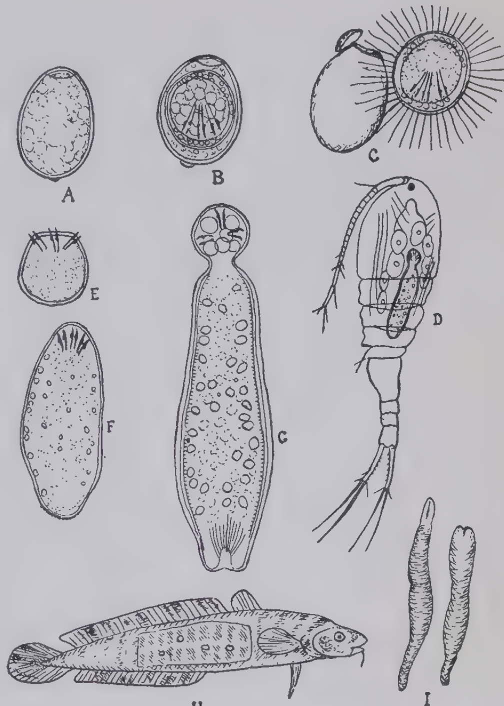


FIG. 125.—Development of *Diphyllobothrium latum* outside of the human body. A, the unripe egg showing the operculum and at the opposite end a rudimentary knob which assists in the diagnosis; B, an egg ready to hatch showing the enclosed hexacanth, ciliated embryo; C, the escape of the embryo (coracidium); D, when ingested by *Cyclops strenuus,* it develops further as shown here in its final stage of development; E, an early stage of the larva after it has lost its ciliated envelope and penetrated into the body cavity of cyclops; F, a growing form; G, the procercoid larva which attains its maximum size after twenty days in body cavity of cyclops; H, a burbot which has become parasitized by ingesting the infected cyclops, the plerocercoids being present in the muscles as well as in the internal organs; I, plerocercoids removed from the fish showing one with scolex extended, the other with scolex invaginated. (From *Oxford Loose-Leaf Medicine.* After Tyzzer and Smillie)

picture in anemia caused by *D. latum* to that of pernicious anemia suggests that a similar mechanism affecting the blood-making system may be present in both diseases.

5. TREATMENT

See page 293.

The recent studies of Minot and Murphy (1926) dealing with the influence of certain liver extractives upon cases of pernicious anemia have suggested similar treatment for clinical cases of *D. latum* infections. Warthin (1928) and others have noted marked improvement hematologically and clinically in patients having severe anemia and *D. latum* infections when treated with a liver fraction diet before the administration of specific treatment for the tapeworm.

6. PREVENTION AND CONTROL

As *D. latum* can be transmitted to man only by the eating of fresh-water fish containing living plerocercoids, personal prophylaxis against this infection consists in the avoidance of improperly cooked, salted, smoked or dried fish or their eggs. Thorough cooking, however, is an adequate protection against *D. latum* for the individual.

Proper disposal of infected feces is a public safeguard. However, the disposal through a water carriage system, with the sewage discharged into a lake or river within a relatively few hours without any preliminary chemical or mechanical treatment is dangerous as the eggs are thus immediately introduced into the habitat of their two necessary intermediate hosts, (1) the copepod, and (2) the fish.

Only a few observations have been made on the resistance of the eggs under unfavorable environmental conditons. Helminth eggs with an operculum are however very susceptible to chemical changes in the environment. Barlow (1925) has shown that the eggs of *Fasciolopsis buski* are readily killed in unslaked lime in dilutions up to 1 to 10,000. Essex (1927) found that the eggs of *D. latum* would not develop in water after previously exposing them for a short time to a 2 per cent solution of formol. The author has observed that the development of the onchosphere is retarded for about one month when the eggs are placed under constant cold-room temperatures and that they may remain viable under such conditions for ten months without hatching. However, upon a short exposure to room temperature, the larvæ quickly escape from the shells and swim about in the water. It is therefore probable that once the living egg reaches cold-water lakes they may remain alive for considerable periods.

Inspection of fish placed on the market for sale has been suggested as a means of public protection against infection with *D. latum.* Such a measure would not be satisfactory since fish is a very unstable article of diet and any detailed inspection would cause more economic loss than the importance of the disease in the United States would warrant. Any superficial inspection of fish is not advisable since plerocercoids when occurring in small numbers are easily overlooked.

Each known case of human infection should be thoroughly investigated to determine the species of fish carrying the infection and the source of the infected fish. Resorters and hunters spending their vacations in endemic areas should be warned against the danger of eating insufficiently cooked fish. The only safe measure against *D. latum* is for the individual to thoroughly cook fish before eating it.

II. *Diphyllobothrium mansoni* (Cobbold, 1882)

1. HISTORICAL

Diphyllobothrium mansoni was known for many years only in its larval stage, the plerocercoid. This plerocercoid was first discovered by Manson in 1882 during an autopsy on a Chinese in Amoy and has since been reported from other parts of the world including Africa, Malay Archipelago, British Guinea, French Indo-China, Annam, Australia and the United States. It is difficult to be certain whether all of these forms reported belong to the same species. These plerocercoids were first placed in the genus *Ligula* by Cobbold in 1882 but were later assigned to the genus *Sparganum,* an artificial collective group containing larval stages of DIPHYLLOBOTHRIINÆ which have not reached a stage in their development that enables one to determine the genera to which they belong. By experimentally feeding some of these larvæ to susceptible hosts, adult stages were obtained which proved that they belonged to a species of *Diphyllobothrium.*

Nothing was known of the life-cycle of this cestode until 1917, when the Japanese scientists Yamada and Yoshida succeeded in obtaining the adult worm by feeding specimens of plerocercoids obtained from the human body to dogs. In about two weeks time they found operculate eggs in the dogs' feces and, at autopsy of these animals, a species of cestode was found which closely resembled *Diphyllobothrium latum.* The complete life-cycle of *D. mansoni* was worked out two years later by Okumura, (1919), and his discoveries were confirmed later by Yoshida (1922).

2. DESCRIPTION

The adult worm in the intestine of the dog and other carnivores closely resembles *D. latum* but may readily be differentiated by the egg (Figure 126), which is definitely spindle-shaped and measures from 63 μ to 75 μ in length by 31 μ to 43 μ in breadth. The plerocercoids found in man and various animals are long, white, somewhat ribbon-shaped parasites and may attain a length of 30 cm., a breadth of 0.1 mm. to 12 mm. and a thickness of 0.5 mm. to 1.75 mm. (Figure 127). The body is transversely wrinkled but shows no segmentation. On the ventral surface there usually appears a longitudinal median groove. The anterior end is the wider. There are no sexual organs present. The plerocercoids are very elastic in the living condition and show but slight movement.

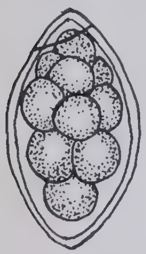


FIG. 126.—Egg of *Diphyllobothrium mansoni* (x 466). (After Okumura)

3. POSITION IN MAN

The plerocercoids may be found in practically any part of the body, especially in the subcutaneous tissues of the abdomen, inguinal parts, outer genitalia, and in and about the kidneys and the pleural cavity. They are also frequently seen about the eye. They occur in a large number of lower animals including monkeys, cats, pigs, rats, domestic fowls, snakes and frogs.

4. LIFE HISTORY

The onchosphere develops within the egg of *D. mansoni* in about eighteen days and emerges in water as a ciliated coracidium. The coracidium is ingested by the cyclops, *Cyclops leuckartii,* and develops into a procercoid within the body cavity of this host. Under normal conditions the plerocercoid stage is passed in the muscles of a frog, *Rana nigromaculata* or a snake, *Elaphe climacophora,* or one of the many susceptible hosts of the plerocercoid which in turn may be food for the final host, the cat or dog, in which the adult stage of the tapeworm is attained. Infection in man is accidentally acquired by swallowing the infected cyclops while drinking.

5. PATHOLOGY

The plerocercoids may cause small inflammatory swelling and abscesses. When present in the orbit, it produces considerable pain,

redness and edema of the eyelids with lacrymation and marked ptosis. This condition is said to occur frequently in and about the Tonkin delta.

III. *Other Species of the Genus Diphyllobothrium*

Two other species of *Diphyllobothrium, D. cordatum* Leuckart, 1863, and *D. parvum* Stephens, 1908, are known to occur in the adult

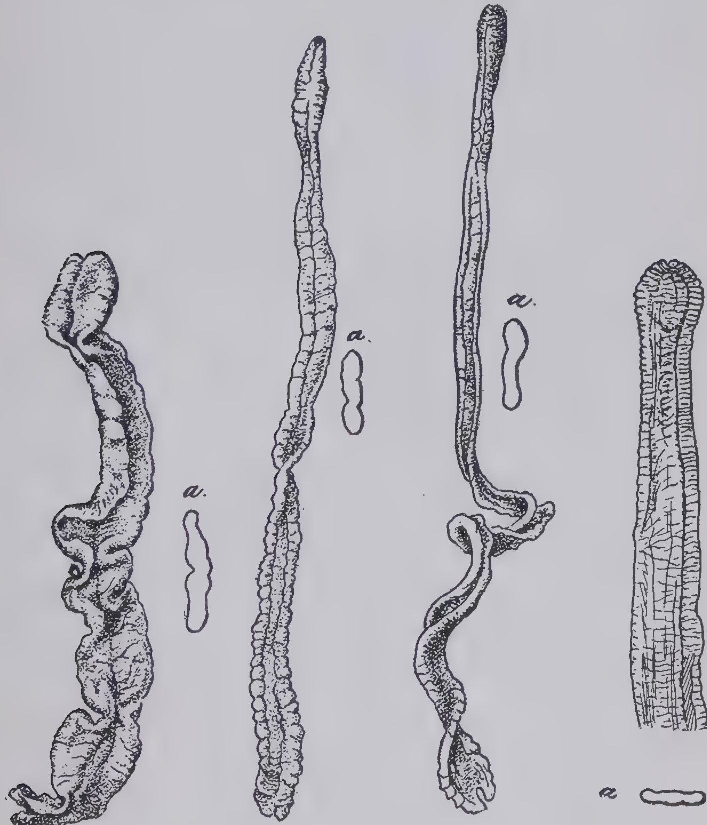


FIG. 127.—*Diphyllobothrium mansoni.* Plerocercoids, natural size. *a*, outline of cross sections. (From Stiles. After Ijima and Murata)

stage in man. *D. cordatum* Leuckart, 1863, occurs naturally in the dog, seal and walrus of Greenland and Iceland and is occasionally a parasite of man. Its presence in man is only accidental. The scolex

of *D. cordatum* is characteristically heart-shaped. *D. parvum* Stephens, 1908, has been found only in man. It was first described from a Syrian in Tasmania and has since been found in man in Japan and Roumania. It is a small tapeworm, the largest segments measuring only 5 mm. by 3 mm. The life histories of these two species are unknown, but it is probable that the plerocercoids are parasites of fish.

Several species of *Diphyllobothrium* have been reported only from lower animals. *D. americanum* Hall and Wigdor, 1918, has been found in dogs in Michigan. This cestode is relatively small, measuring less than 36 mm. in length. It has no neck and the first segment follows immediately back of the scolex. *D. fuscum* was described from dogs in Iceland by Krabbe in 1865 and, according to Neveau-Lemaire (1912), has a compressed lanceolate scolex, a neck slightly narrower than the scolex followed by segments which are at first indistinct. *D. decipiens* Diesing, 1850, has been reported from the cat. These are rare parasites and neither their life-cycle nor pathogenicity is known.

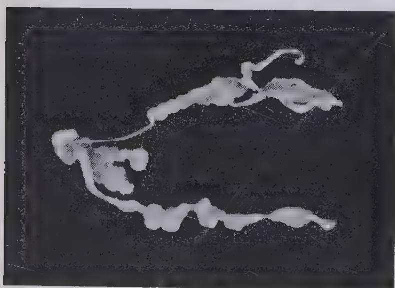


FIG. 128.—*Sparganum proliferum.* Showing buds and supernumerary heads (x 10). (After Stiles)

IV. *Sparganum proliferum* (Ijima, 1905)

Sparganum proliferum is thought to be a plerocercoid of one of the DIPHYLLOBOTHRIINÆ although the adult stage is not yet known. It has been reported several times from man in different parts of the world. It was first observed by Ijima in 1905 in Japan and has later been reported several times from Japanese. It has also been found once in man in the United States (Stiles, 1908).

I. DESCRIPTION

Sparganum proliferum (Figures 128, 129) may attain a length of from 3 mm. to 12 mm. by 2.5 mm. in breadth. The anterior end is narrow and motile and is capable of evagination and invagination. It shows an apical depression. This parasite is characterized by its irregular and bizarre shapes and the supernumerary beads which arise from the parent organism. These beads apparently become detached and wander through the subcutaneous tissue giving rise to

acne-like lesions of the skin. They are also known to migrate into the walls of the alimentary tract, mesenteries, kidneys, lungs, heart and brain.

Exceedingly large numbers of these parasites are usually present in the infected individual. Over 10,000 were found in the left thigh alone in Ijima's case. The infections are usually of several years' standing and may result in death.

The life-cycle of *S. proliferum* is entirely unknown.

FIG. 129.—Showing acne-like condition and enlarged breasts, due to infection with *Sparganum proliferum*. (After Stiles)

V. *The Genus Diplogonoporus* Loennberg, 1892

The genus *Diplogonoporus* differs from other DIPHYLLOBOTHRIINÆ in that its members possess a double set of genital organs with six pores to each proglottid. The scolex is short and broad and is provided with two strong groove-like suckers. The neck is absent. The proglottids are short and broad and clearly show a median field, two uterine fields and two lateral fields. The genital pores, cirrus, vaginal and uterine, occur in longitudinal rows in the uterine field. They are parasites of whales, seals and man.

Two species of *Diplogonoporus* have been reported from man, *D. grandis* from Japan and *D. brauni* from Roumania. Their life histories are unknown.

CHAPTER XXIV

THE ORDER CYCLOPHYLLIDEA

The CYCLOPHYLLIDEA, or tænioid cestodes, are tapeworms characterized primarily by the presence of four cup-shaped suckers upon the scolex. They are further differentiated from the PSEUDOPHYLLIDEA by having the genital pore opening laterally in each segment, the absence of a uterine pore, and their non-operculate eggs in the ripe segments contain a fully developed onchosphere. The onchosphere is never a ciliated larva. One superfamily, TÆNIOIDEA Zwicke, 1841, and at least twelve families may be recognized. Of these twelve families, five are of particular medical importance.

I. *The Family Tæniidæ* Ludwig, 1886

The majority of the more important tapeworms of man and other mammals belong to the Family TÆNIIDÆ Ludwig, 1886. The uterus in TÆNIIDÆ has a median stem with lateral branches when fully developed and forms an outstanding characteristic. The eggs have a thick, radially striated, inner shell, the embryophore, and a thin, deciduous outer membrane, or true egg shell. The female glands occupy the distal portion of the proglottid with the vitellarium median. The rostellum is usually well developed and is generally armed with a double crown of hooks composed of a circlet of large hooks and a circlet of smaller hooks, the larger and smaller hooks being arranged alternately. The suckers are unarmed. There is one set of genitalia in each proglottid and the genital pores are arranged irregularly alternate along the strobila. There are numerous testes. The ovary is bilobed and is sometimes regarded as two (rarely three) ovaries. The adult worms are parasites of mammals and birds.

1. TÆNIA SOLIUM Linnæus, 1758

Historical. Tænia solium is commonly referred to as the "pork tapeworm of man." It, together with other large tapeworms, has been known since very early times. Perhaps one of the earliest records

of these parasites from man is in the Chinese Classical Herbal of the year 1550 B.C., where tapeworm infections are included in a list of maladies and pumpkin seeds recommended as a remedy. The larval stage of *Tænia solium* in swine has also been known for many centuries, but the relation between it and the adult worm remained unknown until about the middle of the nineteenth century. It is very likely that this larva in hogs was largely responsible for the old Mosaic law against the eating of pork (*Leviticus* XI, 8). The Egyptians were also opposed to the eating of pork but their aversion for it was less marked than that of the Jews. The Greeks and Latins, however, regarded the pig as a very unclean animal, but one that was good for food, nevertheless.

It was not until 1855 that the exact nature of these parasites in pigs was understood. Guided by his earlier researches on the development of the dog tapeworm, *Tænia pisiformis,* Küchenmeister reared the adult of *T. solium* from cysticerci (bladder-worms, measles or hailstones) of hogs, and Van Beneden succeeded in obtaining cysticerci in pigs from the onchospheres of Küchenmeister's tapeworm. By these and other experiments Küchenmeister, and later, Leuckart and others were able to expel entirely the former belief that bladder worms were abnormal or incidental parasites.

Distribution and frequency. T. solium has a world-wide distribution which generally corresponds to the distribution of its necessary intermediate host, the pig. Its incidence is in proportion to the amount of raw or insufficiently cooked pork eaten, and the degree of sanitation of the country. It is generally unknown among Jews, Mohammedans and other people whose religion forbids the eating of pork. This parasite is noticeably decreasing in its incidence due to public health campaigns which directly or indirectly affect this parasite.

Description. The adult worm averages from two to three meters in length and occasionally specimens up to eight meters or more have been obtained. The scolex (Figure 130) is globular and is about 1 mm. in diameter. A rather short, but distinct rostellum is present which may be pigmented and which is armed with a double row of from twenty-five to fifty hooks; the larger ones measure about 180 μ and the smaller ones about 130 μ in length. The suckers measure about 0.5 mm. in diameter. The neck is fairly thin and measures from 5 mm. to 10 mm. in length. The first segments are small and broader than long, while those about one meter from the scolex are approximately square. Ripe proglottids are longer than wide and measure about 12 mm. in length and 6 mm. in breadth.

There is but a single set of reproductive organs in each proglottid. The genital pore is marginal and a little below the middle of the proglottid. The genital pores alternate more or less regularly from the right to left margins. The ripe proglottid (Figure 134) is characterized by the uterus which bears from seven to ten rather thick and somewhat ramified lateral branches. The onchospheres are round and from 31 μ to 56 μ in diameter, with a thick, brown, striated embryophore. A thin delicate egg-shell is rarely retained after the

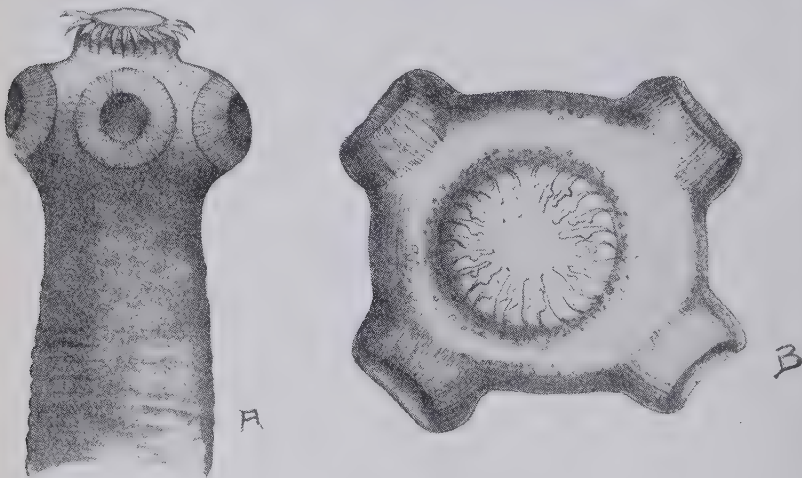


FIG. 130.—Scolex of *Tænia solium*. A, side view (x 45). B, viewed from the front, showing rostellum and double circle of hooks (x 80). (After Leuckart)

eggs leave the proglottid. The ripe proglottids are characteristically expelled passively with the host's feces in chains of from five to six proglottids to a chain. The diagnosis can be readily determined from such portions of the strobila. The adult worm has been found only in man.

Position in the host. The scolex is usually attached to the mucosa of the upper third of the small intestine with the strobila lying backward. This position can, however, be reversed and the proglottids are then discharged by vomiting.

Life-cycle. Upon disintegration of the cast-off proglottids, the onchospheres are set free, become scattered about and may be taken in passively by a susceptible intermediate host with food or water. It is not necessary, however, that the proglottid become disintegrated for infection of the intermediate host as the onchospheres are equally infective within the proglottid. Should the whole proglot-

tid, or several proglottids be ingested by the intermediate host the resulting infection would be enormous. Several different mammals may serve as the intermediate hosts, including man, pigs, wild boars, camels, monkeys, dogs and rats.

Larval infection in man may result from accidental ingestion of onchospheres with food or water or through autoinfection. The onchospheres may be carried to the mouth by soiled hands or by vomiting at which time the onchospheres or whole proglottid may be retained in the stomach and are then in the same position as if they had been introduced through the mouth. The pig is the normal intermediate host and it is probable that the adult stage is reached only by man eating raw or insufficiently cooked pork containing cysticerci. Because of its coprophagous habits the infection in pigs is usually heavy.

The onchosphere is freed from its embryophore in the small intestine of the intermediate host by the dissolving action of the digestive juices, and with the aid of its hooks it penetrates the wall of the intestine and gains entrance into the portal vessels or lymphatics and eventually reaches the peripheral circulation. It leaves the circulatory system in the muscular tissue where it remains, loses its hooks, and becomes an egg-shaped cysticercus from 5 mm. to 20 mm. long. This stage is known as *Cysticercus cellulosæ* (Figure 121) and the infected flesh of the pig is spoken of as "measly pork." The muscles of the pig most often invaded by these cysticerci are those of the tongue, neck and shoulder; then in order of frequency, the intercostals, abdominal, psoas, muscles of the thigh and those of the posterior vertebral region. The liver, heart, lungs, brain and eye may also be parasitized by them.

No further development takes place unless the cysticercus is ingested by man, its only definite host.* When it is taken into the alimentary tract of man the bladder is dissolved by the action of the gastric juices and the scolex is evaginated. It passes into the small intestine where the scolex fixes itself to the wall of the intestine by its suckers and hooks and the development of proglottids begins. The adult stage, with expulsion of proglottids in the feces, is reached in about two or three months after the ingestion of the cysticercus. Life history stages of *T. solium* are illustrated in Figure 131.

Pathogenesis. The adult worm in the intestine of man may produce no outward symptoms but the patient should be treated to

* Schwartz (1928) has observed that considerable growth of *T. solium* may occur in dogs.

expel the worm because of the danger of autoinfection. Infection with cysticerci may bring about serious disorders. In man the cysticerci have been found most frequently in the eye and nervous system. They have also been recorded from skin and cellular portions of the muscular tissues, the heart, liver, lungs and abdominal cavity. The effect upon the host depends upon the number of cysticerci present and their location in the body.

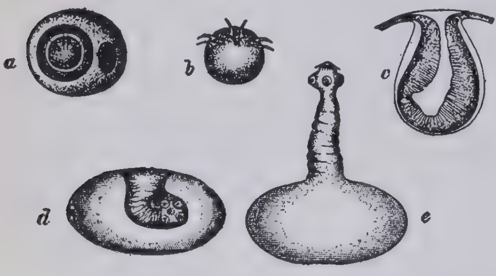


FIG. 131.—Stages in the development of a *Tænia solium*. *a*, egg with embryo; *b*, free embryo; *c*, rudiment of the scolex as a hollow papilla on wall of vesicle; *d*, cysticercus with retracted head; *e*, the same with protruded head. (Partly after Leuckart)

When occurring in the eye they affect most frequently the retina and vitreous body. The initial symptoms are those of ocular irritation which lead up to an enfeebling of the vision and may result in a complete obstruction. When situated in the brain they may bring about congestion and inflammation causing severe headaches, paralysis, and epileptiform convulsions. Cysticercosis in the subcutaneous tissues and muscles of man is exactly the same as "measles" in pork, the normal cysticerci being lodged in the tissue with the long axis of the cysticercus parallel to the muscle fibers. The cysticerci in the muscles usually present no recognizable symptoms.

Diagnosis of cysticercosis. The diagnosis of cysticercosis in man is exceedingly difficult, especially if the cysticerci are situated in the brain or other obscure tissues where they can easily be confused with tumors. The infection in hogs, however, may be determined ante mortem with considerable accuracy by inspection and palpation of the inferior surface of the tongue.

The cysticerci can only be removed from man by surgery and this is often not practical because of either the large number present or because of their position.

Prevention. Government inspection of meats includes an examination for cysticercosis and all infected animals are properly disposed of. However, in view of the fact that this service cannot guarantee pork free from trichina worms, *Trichinella spiralis*, the individual should always safeguard himself by eating pork only when it is thoroughly cooked.

All public health campaigns directly or indirectly affect the spread

of all tapeworms. In connection with the hookworm campaigns, as carried out by the Rockefeller Foundation and various governments in different parts of the world, there is free anthelmintic treatment, which not only expels hookworms, but is also successful in removing other intestinal parasites including the tapeworms. The campaigns also include a constant drive for sanitation and the construction of privies which tend to keep infected feces out of the reach of the intermediate host. It is of interest to note in this connection that following the hookworm campaign of treatment and sanitation by the Rockefeller Foundation and the Panama Government the incidence of measly swine at the Panama City abattoir dropped from 15 per cent to five per cent. This saving of 10 per cent in condemnations for swine effected an annual saving of $40,000 and illustrates but one of the valuable by-products of a hookworm campaign (Hall, 1928).

2. TÆNIA SAGINATA (Goeze, 1782)

Historical. Tænia saginata is commonly known as the "beef tapeworm of man" and has been observed from man for as long a time as has *Tænia solium*, but was not regarded as a distinct species until 1782 by Goeze. Ibn Sina (Avicenna), a famous doctor and teacher of Persia, described "flatworms" in his "Laws of Medicine," about A.D. 1000 (Khalil, 1922) which are apparently *Tænia saginata,* in view of the fact that Mohammedans do not eat pork in any form. Ibn Sina also described symptoms caused by these and other intestinal worms and recommended tar, felix mas, aloes, infusion of peach tree leaves and extract of pomegranate peel as remedies for the "flatworms."

After the discovery that *T. saginata* was a species distinct from *T. solium* studies were soon started on its origin and development. Leuckart (1886) observed that this parasite was especially prevalent in Jews who, like the Mohammedans, are forbidden to eat pork because of religious reasons, and when *T. solium* was found to occur in a Jew, he confessed to having eaten pork. Leuckart also observed that this parasite was frequent in children who had been fed raw beef for dietetic reasons and that the Abyssinians, who eat no swine's flesh, were infected from their earliest years with *T. saginata.* Guided by these observations, he fed about a yard of ripe proglottids of *T. saginata* to a calf four weeks old. Seventeen days later the calf died and at autopsy showed all muscles, especially the breast and neck, full of cysticerci. Later experiments with

other animals showed that cattle only were successful hosts for these cysticerci. Oliver, an Indian army surgeon, was the first to successfully infect human beings with *T. saginata* by feeding cysticerci obtained from beef. In 1869 Oliver (Leuckart, 1886) gave cattle cysticerci to a Mohammedan and a Hindu boy and twelve weeks later obtained from both the proglottids of *T. saginata*. This experiment was later successfully repeated by Perroncito.

Description. The strobilate worm of *T. saginata* (Figure 132) is whitish in color, more or less transparent, and measures from 4 to 10 meters in length. The scolex (Figure 133) is pear-shaped

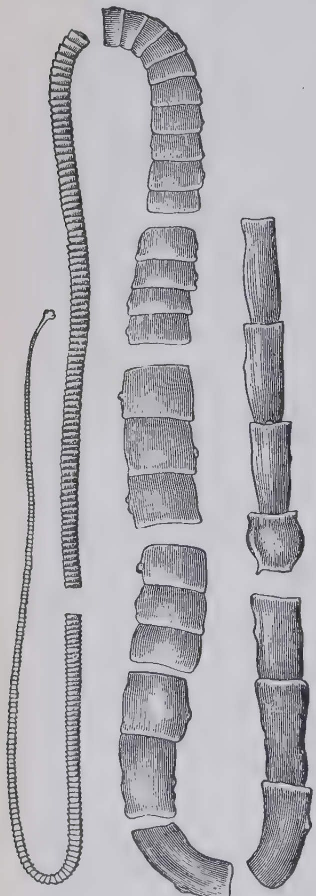


FIG. 132.—*Tænia saginata.* Natural size. (After Leuckart)

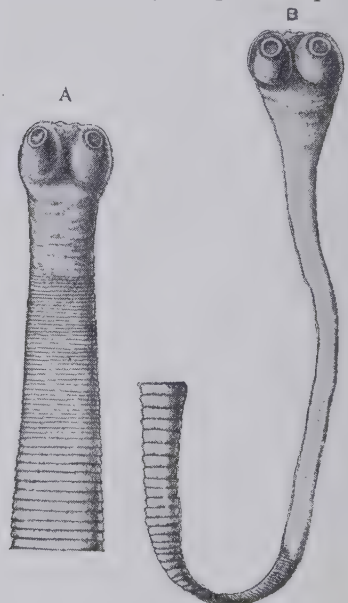


FIG. 133.—Scolex of *Tænia saginata.* A, retracted; B, extended (x 8). (After Leuckart)

or cubical, from 1 mm. to 2 mm. in diameter and bears four prominent suckers which are frequently pigmented. The scolex is without a rostellum or hooks which differentiate it from the pork tapeworm of man, *Tænia solium*. The gravid proglottids (Figure 134) are usually from three to four times longer than they are broad,

having a length of from 16 mm. to 20 mm. The genital pore is single and alternates irregularly between the right and left margins. The uterus in the gravid proglottids characteristically has from twenty to thirty-five lateral ramifying branches. The onchospheres are more or less globular, with the egg-shell frequently remaining intact, and carries one or two filaments. The embryophore is thick, radially striated and somewhat oval, from 30 μ to 40 μ in length and from 20 μ to 30 μ in breadth. The gravid proglottids become detached singly from the strobila and frequently force their way through the anal sphincter. When first passed from the host they show considerable activity and may assume almost any shape. Later on, when quiet, they resemble pumpkin seeds. Because of their ability to force the anal sphincter they are often found in the night clothes and bedding. The chief points of difference between *T. saginata* and *T. solium* are given in the accompanying table.

Abnormal forms, or malformations of *T. saginata* are very common and have been described as

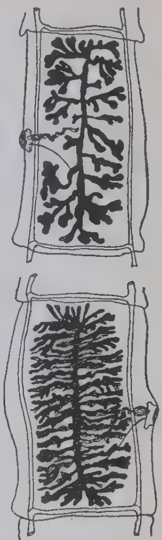


FIG. 134.—Upper figure, ripe or gravid proglottid of *Tænia solium;* lower figure, ripe proglottid of *Tænia saginata.*

Tænia solium	*Tænia saginata*
Scolex globular about 1 mm. in length	Scolex quadrangular 1.5 mm. to 2 mm.
Rostellum with two crowns of hooks	Rostellum and hooks absent
Length 2 meters to 8 meters	Length 4 meters to 12 meters
Number of proglottids 700-1000	Number of proglottids about 2000
Genital pores fairly regularly alternating	Genital pores less regularly alternating
Branches of uterus in gravid proglottids 5 to 10 in number and dentritic	Branches of uterus in gravid proglottids 15-30, dichotomous
Proglottids expelled in groups passively with feces	Proglottids expelled singly and may force anal sphincter
Larval form, *Cysticercus cellulosæ* of the pig, sometimes in man	Larval form, *Cysticercus bovis,* in cattle

new species. These are now known, however, to be aberrant or immature specimens of *T. saginata*. *Tænia fusa* was characterized by the absence of any external segmentation; and the name *T. fenestrata* was proposed for a specimen with perforated or fenestrated proglottids. Bifurcation of the strobila of *T. saginata* has also been observed as well as scolices equipped with six suckers (*T. hybrida*).

Life-cycle. The life-cycle of *T. saginata* is similar to that of *T. solium* except that the development of its cysticercus, *Cysticercus bovis,* takes place in cattle instead of swine. They may also develop in other BOVIDÆ including antelope, giraffe and llama. They have been reported in man but most of the recorded occurrences in man are perhaps due to confusion in specific determination. *C. bovis* is smaller than *C. cellulosæ* and its scolex has no hooks. It occurs in various muscles but more especially in the pterygoids, the fatty tissues surrounding the heart, the diaphragm and the tongue.

Man is the only definitive host and acquires the infection from eating raw or insufficiently cooked beef. When the cysticercus is ingested by man the bladder is dissolved away by the action of the digestive juices and the liberated scolex attaches itself to the wall of the small intestine and proceeds to form proglottids. The adult worm is produced in about three months.

Geographical distribution. T. saginata has a world-wide distribution and its incidence is usually quite high wherever beef is eaten. Its frequency is apparently increasing in the United States, due to the increasing preference for rare beef. *Cysticercus bovis* is commonly met with in slaughtered beef. It is estimated that nearly 1 per cent of all cattle slaughtered in the United States are infected with this parasite.

Pathogenesis. See page 292.

Treatment. See page 293.

Prevention. Thorough cooking of beef will protect the individual from infection with *T. saginata*. The cysticerci in beef are also killed after twenty-one days in cold storage, or after six days if the meat is held at a temperature not exceeding 15° F.

3. TÆNIA CONFUSA (Ward, 1896)

This species (Figure 135) was described from man by Ward in Nebraska and has since been reported by Chandler from Texas.

The scolex is unarmed. It is decidedly oblong in shape and has the suckers grouped into a pair on each side (Figure 135). The strobila consists of from 700 to 800 proglottids, the terminal ones measuring from 25 mm. to 33 mm. in length by 4 mm. to 8 mm. in breadth. Chandler (1920) regards *T. bremneri*, reported from man in Africa, a synonym of *T. confusa* and suggests that it may have been introduced into this country from Africa with slaves.

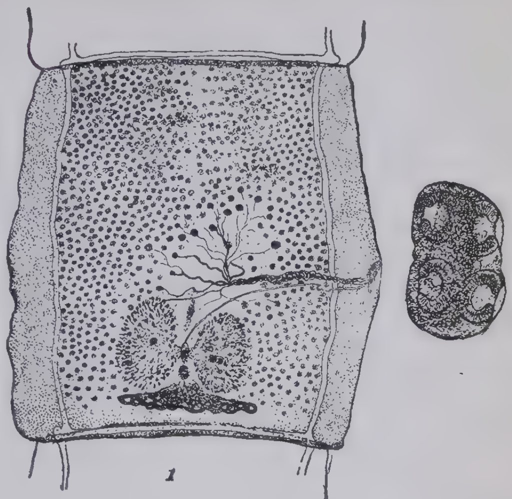


FIG. 135.—*Tænia confusa*. *1*, proglottid somewhat beyond sexual maturity; *2*, scolex, viewed from anterior end to show oblong shape and bilateral arrangements of suckers. Magnified. (After Chandler)

4. TÆNIA INFANTIS (Bacigalupo, 1922)

Tænia infantis was obtained from a child five years old in a hospital in Buenos Aires, Argentine, and was described by Bacigalupo. The worm is about 30 cm. long and composed of about 200 segments, with the genital pores arranged irregularly alternate. The head measures about 3 mm. in diameter and is provided with two rows of thirty-five to forty hooks from 260 μ to 410 μ in length.

5. OTHER IMPORTANT TÆNIA

Tænia pisiformis (Bloch, 1782) is one of the commonest tapeworms of dogs and cats and is one that is readily available both for morphological and life history studies. The bladder-worm is known as *Cysticercus pisiformis* and develops in the liver and mesenteries of rabbits. The development of this parasite has already been discussed on page 290.

Tænia ovis (Cobbold, 1869) is a common parasite of dogs. Its

bladder-worm, *Cysticercus ovis*, develops in sheep and is essentially a parasite of the intermuscular connective tissue. It is of considerable economic importance because of the losses resulting from the condemnation of carcasses found infected by the Federal Meat Inspection Service. Over 17,000 of the sheep slaughtered during 1917 under Federal supervision were found infected with *C. ovis* (Ransom, 1913). Direct losses which may occur among sheep as a result of the invasion of the parasite may be considerable. As *C. ovis* is not transmissible to man, the precautions taken in the preparation of lamb as food need not be as stringent as those for pork.

Tænia hydatigena (Pallas, 1766) (Figure 115) is also a cosmopolitan parasite of dogs with the larval stage in sheep. This larva, *Cysticercus tenuicollis,* develops in the liver and, after a certain stage is reached, slips into the abdominal cavity where it is found surrounded by an adventitious cyst attached to the mesenteries or omentum. It does not affect the musculature of the sheep and it is therefore not of the same economic importance as *T. ovis. Cysticercus tenuicollis* may also develop in cattle, deer, moose and pig.

Preventive measures against dog-sheep tapeworms. All carcasses of dead sheep on the farm or range should be destroyed by fire so that they may not be eaten by dogs or wolves. Dogs should be kept free from tapeworms by systematic medicinal treatment. These measures would also aid in the protection of sheep and other susceptible hosts from various tapeworm cysts which they acquire from dogs.

Fig. 137.—*Cysticercus fasciolaris.* Natural size. (After Leuckart)

Tænia crassicollis (Rud., 1810), more commonly known as *Tænia tæniæformis,* is a very common cestode of the domestic cat and has been reported also from a number of different wildcats (Figure 136). Its larval stage, or bladder-worm, is generally known as *Cysticercus fasciolaris* of rats and mice is a *strobilocercus* (Sambon, 1924). It is characterized by a very small bladder or vesicle filled with a fluid and a very long strobilate connection between this caudal bladder and the scolex (Figure 137). In this larva we therefore find considerable development toward the strobilate or adult stage while it remains in the

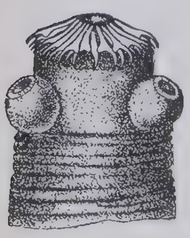


Fig. 136.—Scolex of *Tænia crassicollis* (x 15). (From Hall. After Neuman)

tissues of the intermediate host. Neither the adult worm nor the larva is of economic importance, but the larva is of particular interest because of its association with sarcomatous growths in the liver of rats. Under natural conditions it is frequently found enclosed in such tumors. Recently Bullock and Curtis (1920) produced a large number of cases of sarcoma of the rat's liver by feeding rats the onchospheres of *T. crassicollis*. The tumors arose from the encapsulating tissue surrounding the bladder-worms.

A number of other species of *Tænia* are known from dogs and cats, the more important are *T. balaniceps* Hall, 1910, from dogs and bobcats of Nevada and Southern New Mexico; *T. krabbei* Moniez, 1879, from dogs of Iceland and Alaska; *T. brachysoma* Setti, 1899, from dogs of Italy; *T. brauni* Setti, 1897, from dogs of Eritrea; *T. laticollis* Rudolphi, 1819, from the European lynx; *T. macrocystis* Luehe, 1910, from mountain lions and bobcats of Brazil, Paraguay and the United States; and *T. monostephanos* von Linstow, 1905, from the lynx of Russia.

6. ECHINOCOCCUS GRANULOSUS (Batsch, 1786)

Distribution and frequency. Echinococcus granulosus is a common parasite in the adult stage of dogs, wolves and jackals. It may also occur in cats. It is cosmopolitan in distribution, occurring frequently in Mecklenburg and Pomerania, North Germany; Iceland, Algeria, Tunis, Egypt, Abyssinia, Cape Colony, Arabia, Australia (especially in the province of Victoria), and in Argentina, Uruguay, and Chile in South America. It is apparently quite common in some parts of the United States as judged from the presence of its larva which is not infrequently met with in the meat inspection service of the United States Bureau of Animal Industry.

Description. This parasite in the adult stage is the smallest tapeworm of medical importance, measuring between 3 mm. to 6 mm. in its total length (Figure 138). The scolex is very small, somewhat globular and measures about 300 μ in diameter. There is a prominent rostellum which is armed with a double crown of twenty-eight to fifty hooks. The larger hooks measure from 22 μ to 30 μ in length and the smaller ones from 18 μ to 22 μ. The suckers are 130 μ in diameter and are set well back from the rostellum. The neck is short. The strobila consists usually of only four proglottids, never more than four. The first proglottid is nearly square. It measures about 260 μ in length and 240 μ in breadth and is

sterile. The second proglottid is about twice as broad in its posterior portion as the first segment and is about four times as long, and is mature. The third, or last segment, may attain a maximum length of 2 mm. and a width of 600 μ and is gravid. The uterus is tubular and the median stem has short, more or less indistinct, lateral enlargements. The eggs are slightly oval in shape, 32 μ to 36 μ in length by 21 μ to 30 μ in breadth. The embryophore is moderately thin with thin radial striations.

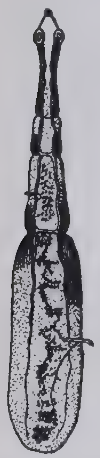


Fig. 138.—*Echinococcus granulosus*, adult worm from the dog's intestine. Enlarged. (After Leuckart)

Life-cycle. The eggs produced by the adult worm in the intestine of the dog or other suitable primary host, are passed out with the feces and are ingested, as a rule, by the intermediate host with contaminated food or water. A large number of different mammals may serve as the intermediate host for *E. granulosus* including man, monkeys, cattle, sheep, goats, camels, antelopes, pigs, cats, dogs, panthers, bears, rabbits, squirrels, tapirs, zebras, horses, donkeys and the giant kangaroo. The peacock and turkey cock also have been reported as possible intermediate hosts for this parasite but these need confirmation.

The onchospheres hatch in the stomach and small intestine and actively penetrate the wall into the lymphatics and small radicles of the portal vein whence they are then carried to various tissues where they develop into a larval stage, a bladder-worm commonly called an echinococcus or hydatid cyst. This larva most frequently develops in the liver, lungs, kidney, peritoneum, brain or genitalia but occasionally has been encountered in the heart, the long bones and in the orbital cavity. In young pig's liver the onchosphere tends to come to rest in the substance of the hepatic lobule and according to Dew (1925) shows a striking predilection for those lobules situated close under the peritoneal coat.

The onchospheres may reach the liver as early as twelve hours after ingestion and their presence there causes an early local reaction of the liver tissue by which the hydatid follicle is produced. Vesiculation may commence about two weeks after infection and thus soon forms a laminated external membrane and an internal germinative or parenchymatous layer. The growth of the hydatid is exceedingly slow. At the end of five months it may reach a diameter of about 1 cm., but there is at this time no trace of the formation

of scolices or other internal structures. As the bladder increases in size, the liver cells in contact with the outer laminated membrane are gradually pressed upon. They undergo atrophy and pressure necrosis and are finally converted into a fibrous tissue or adventitious layer. A few months later the cyst has increased in size by the accumulation of fluid and begins to produce brood capsules (Figures 139-140).

Completely developed hydatids vary considerably in size. In the hog they are usually from 4 cm. to 5 cm. in diameter while in man they may attain the size of a child's head. This size difference is probably due to age differences. When found in lower animals, it is in those slaughtered for food, and in such cases the hydatids are not old enough to have reached full development. When found in man the infection may have existed for many years. When uninfluenced by pressure the hydatid is more or less spherical in shape and is made up of the following parts (Figure 141):

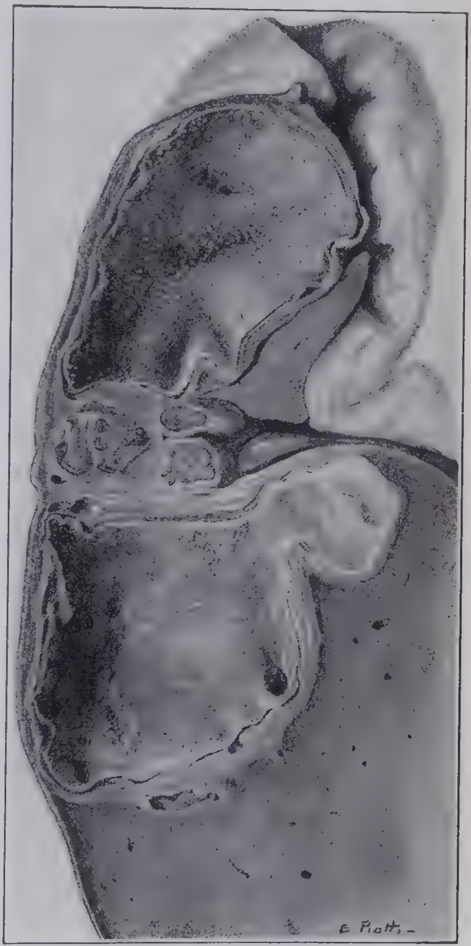


FIG. 139.—Cut surface of a pig liver showing intense infection with fertile hydatids. (Original)

1. An external laminated cuticle.
2. An internal germinative or parenchymatous membrane.
3. A fluid which distends the bladder.
4. Brood capsules containing scolices.
5. Daughter cysts.

The external cuticular membrane of the hydatid is formed by the original cells of the germinative layer and acts as a support for the delicate germinative or inner nuclear layer. It is more or less hyaline and may attain a thickness of about 1 mm. It is a

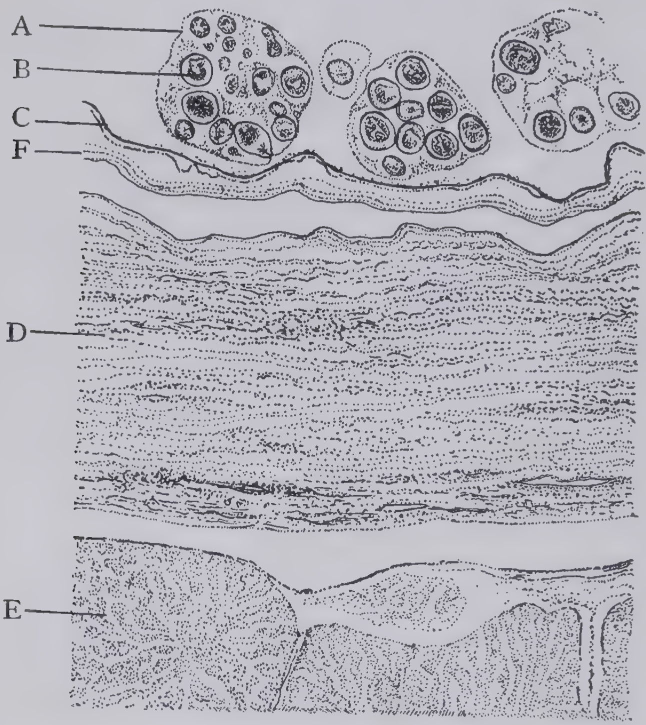


FIG. 140.—Section of a fertile hydatic cyst in the liver of a pig. A, brood capsule; B, scolex; C, germinal layer; D, adventitia; E, liver tissue; F, laminated cuticle. (Original)

permeable membrane and apparently has a selective action which insures retention of the specific fluid and the entry, by osmotic processes, of a supply of necessary substances for the growth of the parasite. This cuticular membrane also has a protective action in preventing the entry of noxious substances. The contents of the cysts may remain sterile even after several days immersion in various bacterial cultures. Since this layer is first formed it becomes greatly stretched as the hydatid increases in size. When it is incised or ruptures, it contracts and rolls up, because of its elasticity,

and the cysts turn inside out, thus setting the brood capsules and small daughter cysts free. This is a characteristic of hydatids.

The internal germinating layer (Figures 140-141) is an exceedingly delicate structure measuring from 22 μ to 25 μ in thickness. It is made up of a large number of nuclei embedded in a protoplasmic matrix which is rich in glycogen. It also contains some muscular fibers and calcareous bodies. On its inner surface

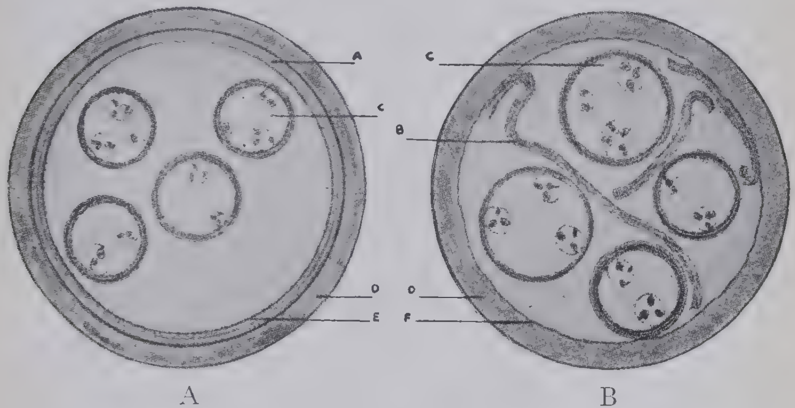


FIG. 141.—The arrangement of the original mother cyst and daughter cysts. A, the generally accepted view; B, the view according to Dew. A, laminated membrane; B, laminated membrane lying free amongst the daughter cysts; C, daughter cysts containing scolices; D, adventitious capsule; E, germinal or inner nucleated layer; F, rough inner coating of adventitia in typical cases of daughter cyst formation. (After Dew)

there appear groups of small papillæ, the brood capsules in various stages of development.

The bladder is filled with a colorless or somewhat yellowish fluid, hydatid fluid, which has a specific gravity of 1007 to 1015. This fluid may contain sodium chloride to the extent of 0.5 per cent and phosphates and sulphates of soda, succinates of sodium and calcium, sugar, inosite and albumin which are not coagulated. It therefore functions as a buffer and protects the developing scolices. The hydatid fluid is sterile due to the perfect filtering action of the outer cuticular membrane but should the cyst wall become ruptured the liquid makes an excellent medium for the growth of pathogenic bacteria.

Brood capsules usually appear on the inner surface of the germinative membrane about eight months after the beginning of the

cyst formation. They are at first papillary vesicles and are attached to the germinative membrane by a short pedicle. As the vesicle enlarges there develop on the inner surface a number of small oval bodies or scolices from fivè to twenty or more, which, when completely formed, measure about 0.1 mm. in diameter and distinctly show the suckers and a double crown of hooks. Often the scolices break out of their brood capsules and are found free in the hydatid liquid. When these are obtained upon sedimentation of the hydatid liquid they are spoken of as "hydatid sand." Hydatids in which no brood capsules or scolices have developed are frequently found in man. Such specimens are commonly referred to as sterile cysts or acephalocysts.

Very often in human subjects, and occasionally in animals, there is a formation of daughter cysts within the original mother cyst, and these daughter cysts, although smaller, have the same histological structure as the mother cyst. Again, in some cases, these small daughter cysts may contain several smaller cysts or grand-daughter cysts. Several theories have been formulated to explain this phenomenon and it now appears that this daughter cyst formation is the result of some accident or interference with the normal development of the parasite. It may be regarded as a defensive reaction to insure the carrying on of the species when the activity of the germinal cells of the parasite are vitally menaced and the continued production of scolices becomes impossible.

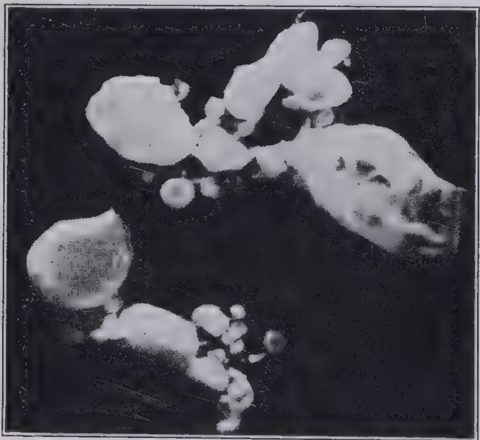


FIG. 142.—Growth of daughter cysts from scattered islets of germinal cells in germinal membrane which has become detached. (After Dew)

Daughter cysts may arise from the germinal membrane, brood capsules or from the scolices. Apparently their origin is most frequently from the germinal membrane and brood capsules. The delicate germinative membrane is but lightly adherent to the laminated cuticular layer and may separate very readily after slight trauma or other disturbance. It then floats freely in the hydatid fluid

and islets of germinal cells may lay down fresh protective laminated layers and produce fluid, forming small daughter cysts (Figure 142). Brood capsules may separate from the germinative layer and float freely in the cyst fluid. An outer, protective layer is then laid down and the cyst increases in size and becomes more rigid. According to Dew (1926) it is probable that such activity is largely limited to young brood capsules which are still growing and give rise to new scolex buds. Nauyn (1862) first described vesicular changes in the scolex leading to the formation of daughter cysts which were also observed by Dévé in 1901. Dévé regards the transformation as a progressive evolution from one state to another. Dew (1926) obtained daughter cysts in rabbits by using active scolices from cysts of sheep. Dew however regards the fully developed scolex as an end product and questions any development of cysts from it; he thinks it more likely that secondary cyst formation proceeds from relatively undifferentiated scolex buds.

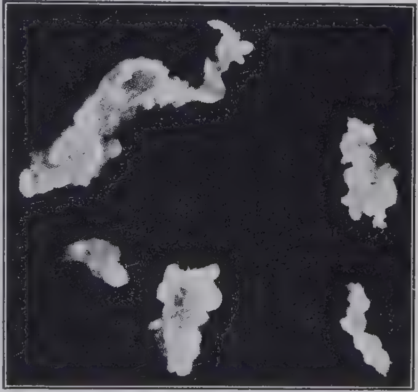


FIG. 143.—Hydatid cyst dissected from decalcified bone. The specimen shows multiple pouchings along bony canals. These latter may become cut off with the formation of small cysts. (After Dew)

The formation of daughter cysts by the inclusion of islands of original germinative tissue in the laminated cuticular layer leading to the formation of so-called "exogenous daughter-cysts" has been described by Leuckart and other authorities. They are said to arise as follows: Bits of the original germinal cells, which in some way have become included in the laminated layer, begin to multiply and form a separate cuticle, and, as the size increases by the formation of additional layers, it becomes vesicular and gradually approaches the external surface of the mother cyst and later comes to lie free between the adventitia and parent cyst. This newly formed cyst may succumb to pressure or increase in size and later acquire its own adventitia. Exogenous daughter cysts occur frequently in secondary echinococcosis of the omentum and of bone. Dew (1926) explains the formation of exogenous cysts by an external herniation of both the laminated and nucleated layers through relatively weak portions of the adventitia as a result of rising intracystic pressure.

The pouch thus formed increases in size and finally becomes constricted until it closes off forming a small cyst which remains attached by its cuticle to the original mother cyst (see Figure 143). According to Dew the eversions may be multiple and tertiary and even quaternary cysts may arise in this manner.

Secondary echinococcosis. Through traumatic rupture, puncture or imperfect operative technic the scolices, bits of germinal cells, daughter cysts and brood capsules may be set free from the mother cyst and when implanted in other tissues of the body may give rise to secondary cysts. Secondary omental and abdominal hydatids often arise following a leakage of a primary cyst into the abdominal cavity and, because of the influence of gravity, they occur frequently in the pelvic cavity. They vary considerably in size, generally have but little support from their adventitia and hang almost freely in the peritoneal cavity. Hydatid emboli may occur when the blood capsules and scolices are carried by the blood stream and form metastases in new situations. When a peripheral cyst of the spleen or liver breaks into one of the systemic veins, the secondary cysts usually occur in the lung. Should the primary cyst occur in the right heart, the metastatic cysts may also occur in the lung, but if it is located in the left heart, the resulting cysts develop mostly in the brain, or the spleen, kidney or liver. The metastatic cysts are as a rule multiple. According to Dew, most hydatids of the brain in young people are single and primary but those occurring in adults are often multiple and secondary to a cyst of the left side of the heart.

The end product of the hydatid is the scolex and each scolex has the power to develop into the strobilate worm when ingested by dogs or wolves, the primary hosts. As a single hydatid may contain thousands of brood capsules, and each capsule may give rise to a comparatively large number of scolices, the number of strobilate worms resulting from the ingestion of one hydatid may be enormous. The strobilate stage is reached in the intestine of the dog in from four to ten weeks after the ingestion of the hydatid. Apparently dogs become most frequently infected by eating hydatids from sheep. Heavily infected animals show an intense intestinal catarrh and may die from acute helminthiasis.

Pathology. The presence of the hydatid soon provokes an inflammatory reaction and as the cyst increases in size the normal tissue cells are pressed upon and undergo atrophy and pressure

necrosis and make up the adventitious layer. Its intimate fusion with the normal tissue prevents enucleation of the adventitious capsule with the contained hydatid cyst at operation.

Symptoms. The symptoms produced by the hydatid cyst are comparable to those of a slow growing tumor and often too vague for recognition, especially when occurring in the liver. In certain cases, anaphylactic symptoms may arise following an accidental rupture of the cyst and absorption of the hydatid fluid.

Diagnosis. If the cyst is near the surface, a fluctuation may be determined which is a characteristic of the hydatid. Until recently the suspicion of hydatid cysts was regularly tested by puncture of the cyst with an exploratory syringe to determine whether the fluid contained characteristic scolices or hooks which would permit a positive diagnosis. Such a procedure is, however, exceedingly dangerous in view of the possible introduction of pathogenic bacteria into the sterile fluid of the cyst and spilling of scolices and brood capsules, thereby producing secondary echinococcosis and toxic symptoms, caused by absorption of the hydatid fluid. The exact position of the cyst may be determined under the X-ray.

Welsh, Chapman and Storey (1909) devised a precipitin reaction for the diagnosis of hydatid infections and used fresh human hydatid fluid as antigen. Fairley (1923) found carbolized hydatid fluid from sheep a satisfactory stable antigen. The addition of carbolic acid up to 0.45 per cent prevents bacterial growth during the test and allows the tubes to be read after thirty-six hours. Equal parts of the preserved hydatid fluid and serum of the suspected case are layered and if the case is positive a precipitate is formed after one hour at 37° C.

A complement-fixation test which is precisely similar in principle to the Wassermann test for syphilis is also used in the diagnosis of hydatid infections. Alcoholic or saline extracts of scolices make stable and sensitive antigens.

The intradermal or Casoni test (Casoni, 1912) is said to be superior to that of the complement-fixation reaction. In this test 0.5 c.c. of filtered hydatid fluid is injected intradermally in one forearm and the same amount of saline in the other. A positive result consists in the production of an urticarial wheal followed by erythema and swelling within three to twelve hours. As the erythema extends the wheal disappears and the erythema may last for forty-eight hours. No systemic reaction is elicited.

A knowledge of the geographical distribution of the disease and occupational predispositions of the individual are of fundamental importance in the diagnosis.

Treatment. Hydatids can be treated only by operative measures. Aspiration may cure simple cysts but is dangerous in that secondary echinococcosis, anaphylactic symptoms and suppuration may result from it. Because of the risks of spilling small daughter cysts, brood capsules or scolices during evacuation of hydatids, a preliminary formalin injection may be made into the cyst contents. This method consists of evacuation under sight by means of a trocar of a quantity of fluid followed by the injection of an equal amount of 2 per cent to 5 per cent formalin. The formalin causes death and fixation of the brood capsules and scolices within a very short time. For lung hydatids other fixative agents such as mercury perchloride or alcohol may be used. This method is most applicable to simple cysts but is of little value in cysts containing daughter cysts as the laminated membrane is very resistant and is difficult to fix quickly and thoroughly.

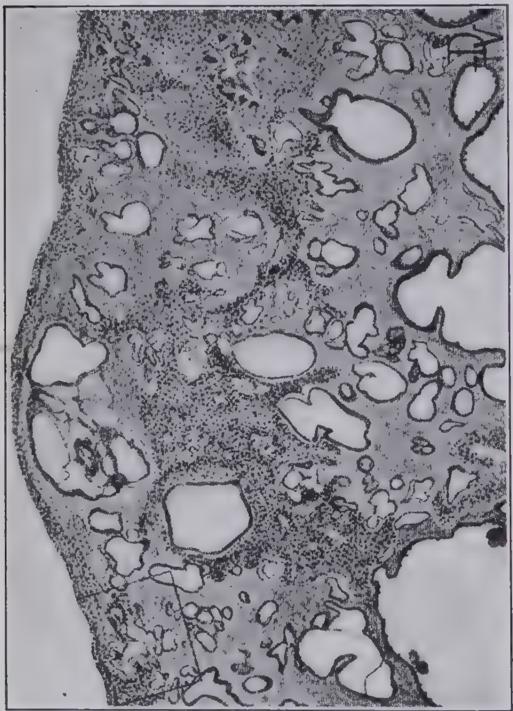


FIG. 144.—Section of an alveolar cyst in man caused by *Echinococcus multilocularis.* (After Dévé)

Prevention. Prophylactic measures discussed against *Tænia hydatigena* are equally applicable against *Echinococcus* in dogs. In endemic centers dogs should not be fed on raw meat and all pariah dogs should be killed. Close contact with dogs by man should be avoided and all food exposed to contamination must be cooked to

insure the death of the onchospheres. Water should be boiled for drinking purposes.

7. ECHINOCOCCUS MULTILOCULARIS Leuckart, 1863

Echinococcus multilocularis in the strobilate stage is also a parasite of dogs with larval stages in various mammals, including man. It is distinguished from *E. granulosus* mainly in the character of its cystic stage, the hydatid. It also has a distinct and separate geographical distribution occurring most frequently in Southern Bavaria, the Tyrol, Würtemberg, and Northern Switzerland, Russia and Siberia.

Apparently the initial larval stages of *E. multilocularis* follow much the same lines of development as those of *E. granulosus* to a certain stage at which time the original cyst sends off germinal buds. These buds become multilocular or alveolar cysts with cavities filled with a gelatinous material. Many of the cysts contain no scolices. The liver is generally the seat of infection and, by means of metastasis, cysts may reach other organs especially those of the abdomen and the lungs and heart. The infected organs have a honeycombed appearance due to the character of the growth of the cysts (Figure 144). Surgical treatment is almost impossible and the infection almost always leads to premature death.

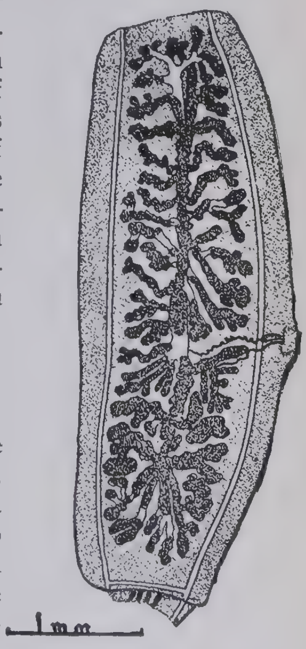


FIG. 145.—*Multiceps multiceps.* Gravid segment. (After Hall)

8. MULTICEPS MULTICEPS (Leske, 1780)

Description. Multiceps multiceps in the adult stage is a common parasite of dogs. The scolex is about 1 mm. in diameter and bears a double crown of twenty-two to thirty-two hooks, the large hooks are from 150 μ to 170 μ long. The small ones measure from 90 μ to 130 μ in length. A gravid segment is illustrated in Figure 145.

The larval stage is a cœnurus, commonly known as *Cœnurus cerebralis* (Figure 146) which normally develops in the central nervous system of sheep goats and other ruminants. It has also been reported from man.

Life-cycle. The onchospheres developed by the adult worm in the intestine of the dog pass out and are ingested in contaminated food or water by the intermediate host. The onchosphere is released from its shell in the digestive tract and bores its way through the tissue and into the blood stream. Larvæ which attain the central nervous system develop into the cœnurus stage. Others which do not reach the central nervous system may begin development, but very soon die and undergo degeneration. The cœnurus consists of a membranous vesicle which may vary in size from a filbert to that of a hen's egg and usually takes on a spherical form. The wall is thin, translucent and distended by a colorless fluid. On its surface there are small irregularly grouped spots and each individual spot represents an invaginated scolex. On the death of the sheep, as a result of the pressure of the cœnurus or from other causes, the cyst may be ingested by dogs. When this happens each scolex attached to the vesicle may develop into an adult worm.

FIG. 146.—*Multiceps multiceps.* Cœnurus from brain of sheep. Enlarged. (After Hall)

Pathogenesis. The adult worm in the intestine of dogs is of no importance but the larval stage in sheep produces a fatal disease commonly known as gid or staggers. Early in the infection the sheep shows dullness and somnolence and there is usually a rapid loss of flesh. Visual disturbances are soon noticed. The head is held in a peculiar position and the animal turns in circles or may stagger and stumble about, repeatedly falling. These symptoms are not continuous. They may appear several times a day with intervals of comparative rest. Unless the cœnurus is removed by surgical means, the animal passes into a state of complete paralysis and dies from exhaustion or in convulsions.

Prevention. See page 320.

9. MULTICEPS SERIALIS (Gervais, 1874)

Multiceps serialis, like *M. multiceps,* is also a common parasite of dogs. Its larval stage, *Cœnurus serialis,* is a parasite of rabbits, hares, squirrels and other rodents. *Cœnurus serialis* develops in the connective tissue under the skin and between the muscles, and is further characterized by the production of internal and external daughter bladders which in turn develop numerous scolices. The dog becomes infected by ingesting these scolices which develop segments and form the strobilate worm.

II. *The Family Davaineidæ* Fuhrmann, 1907

The family DAVAINEIDÆ is characterized by the presence of numerous small, hammer-shaped hooks arranged in a double row

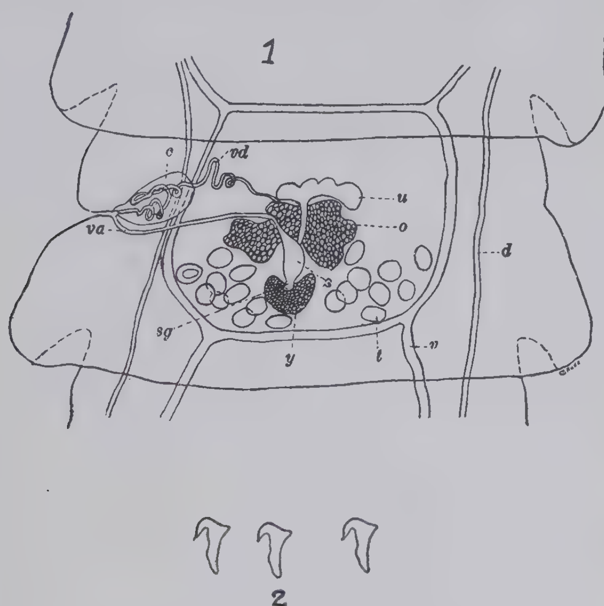


FIG. 147.—*Davainea cesticillus.* 1, mature proglottid (x 103); 2, rostellar hooklets (x 480). (After Ackert)

on the rostellum. The suckers are also usually armed. There may be either a single or double set of reproductive organs in each segment with the genital pores marginal, and bilateral, unilateral or

irregularly alternating. The uterus is sac-like, persistent; or sac-like or branched, not persistent, replaced either by numerous egg capsules or by a single egg capsule whose formation is preceded by the appearance of a paruterine organ. The onchosphere is surrounded by two thin, transparent membranes. The adults are normally parasites of mammals and birds, mostly of scratching birds.

Only three species of this family have been reported from man, (1) *Davainea asiatica* (Linst., 1901), from Russian Turkestan; (2) *D. formosana* Akashi, 1916, from Formosa and Japan, and (3) *D. madagascariensis* Dav., 1870, from British Guiana, Mauritius, Siam, the Philippine Islands, Noissi-Bé and Madagascar. The life histories of these parasites are unknown. The cockroach has been suspected of being a vector.

Davainea has a world-wide distribution in domestic fowls, occurring most frequently in chickens, turkeys, guinea fowls, pheasants and pigeons. In the United States, *D. tetragona* Molin, 1858; *D. cesticillus* Molin, 1858 (Figure 147); *D. echinobothrida* Mégnin, 1881, and *D. proglottina* Dav., 1860, appear to be common species. *D. celebensis* Janicki, 1902, is a parasite of rats.

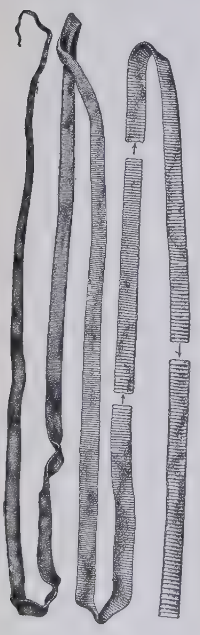


FIG. 148.—*Moniezia trigonophora.* About one-half natural size. (After Stiles)

III. *The Family Anoplocephalidæ* Kholodk., 1902

The ANOPLOCEPHALIDÆ are very muscular cestodes. The scolex is usually rather large, globular and is never armed with hooks. There is no rostellum. The strobila is also relatively large and plump with the genital pores marginal, bilateral, unilateral or irregularly alternate. The genitalia may be single or double in each segment. The uterus lies transversely in the segment and is an elongated sac with pocket-like appendages, anteriorly and posteriorly. The eggs usually have a well-developed pyriform appa-

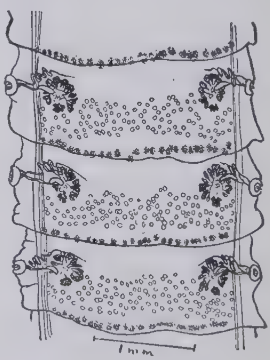


FIG. 149.—*Moniezia expansa.* Mature proglottids, showing interproglottid glands. (After Theiler)

ratus. The ANOPLOCEPHALIDÆ are parasites of mammals and birds. They are frequent parasites of sheep, cattle and goats.

One species, *Bertiella satyri,* R. Blanchard, 1891, has been reported from man in Mauritius. There is but a single set of reproductive organs in each segment of this species.

Moniezia expansa (Rudolphi, 1810) Blanchard, 1891, *M trigonophora* Stiles and Hassall, 1893, and *M. planissina* Stiles and Hassall, 1892, are very common parasites of sheep and may also occur in other Ruminantia (Figures 148 and 149).

The Moniezias are whitish to yellowish in color and may attain a length of several yards. The individual proglottids of the worm are broader than long and each contains two sets of reproductive organs. The genital pores are bilateral. Interproglottid glands are usually well developed and stain readily.

The life history of the *Moniezia* is not known. It seems very probable that the intermediate hosts are insects that may be ingested with grass by the sheep. There is no evidence that such is the case, however.

Thysanosoma actinioides Diesgin, 1834, or the fringed tapeworm (Figure 150) is a very frequent parasite of range sheep of Western United States, including North and South Dakota, Nebraska, Kansas, Oklahoma, Texas and the States west of these. This parasite may attain a length of one foot but is commonly shorter. It is readily distinguished from other tapeworms by the fact that each of the proglottids has a fringe on its posterior border. There is a double set of reproductive organs but only a single uterus in each segment, with opposite or with irregularly alternating pores, those on one side, with the corresponding cirrus pouch, ovary and vagina having been suppressed. It is frequently found in the gall ducts, gall bladder, biliary canals of the liver and in the duct of the pancreas as well as in the small intestine. It may cause obstruction of the bile ducts and pancreatic ducts and derange-

FIG. 150.—*Thysanosoma actinioides,* the fringed tapeworm of sheep. About natural size. (After Stiles)

ment of the liver resulting in impaired digestion, loss of flesh and poor quality of flesh and wall. Its life history is unknown but it is presumed that an insect or other small animal serves as an intermediate host.

Anoplocephala perfoliata Goeze, 1782; *A. plicata* Zeder, 1800; and *A. mamillana* Mehlis, 1831, are known to occur in horses in Europe. Tapeworms are, however, very rare in horses and are of no economic importance.

IV. *The Family Hymenolepididæ* Rail. and Henry, 1909

The HYMENOLEPIDIDÆ are small to medium sized tapeworms with proglottids broader than long. The scolex may be either armed or unarmed. When hooks are present they are not hammer-shaped as in *Tænia*. The suckers are usually unarmed. The neck is short. There is usually only a single set of reproductive organs to each proglottid, with the genital pores marginal and unilateral. One to four testes are normally present in each proglottid. The eggs have thin transparent shells. The adult worms are parasites in mammals and birds.

1. HYMENOLEPIS NANA (von Siebold, 1852)

Historical. Hymenolepis nana is commonly known as the "dwarf tapeworm." It was first described by Dujardin in 1845 from rats under the name *Tænia murina*. It was first discovered in man by Bilharz in 1851 during autopsy of a boy who had died from meningitis in Cairo, Egypt. Bilharz called it *Tænia egyptica*. Von Siebold, however, was the first to describe the parasite, from material sent him by Bilharz, and gave it the name of *Tænia nana*. This Egyptian case was the only one reported from man for many years but now it is known that this parasite is cosmopolitan and a very common one of man, rats and mice. It is especially frequent in children. Grassi (Grassi and Rovelli, 1892) believed that development of *H. nana* was direct, i.e., that the intermediate host was omitted. He demonstrated that mature segments or onchospheres of *H. nana* from rats when fed to rats develop into small larvæ in the intestinal wall and when fully developed break out into the lumen of the intestine and grow into strobilate worms. These observations have since been confirmed many times. The identity of the rat and human specimens was long disputed. It was held that although morphologically alike they were physiologically distinct. Recent experiments by Woodland (1924) and others have shown,

however, that cross infections are possible, and they are generally regarded now as one species.

Description. The strobilate worm (Figure 151) measures from 10 mm. to 45 mm. in length and from 0.5 mm. to 0.7 mm. in breadth. The scolex is globular, about 0.25 mm. in diameter and the rostellum is equipped with a single row of twenty-four to thirty hooks which are from 14 μ to 18 μ in length. The strobila consists of about 200 proglottids measuring from 0.4 mm. to 0.9 mm. in breadth and 0.014 mm. to 0.03 mm. in length. There are three testes in each proglottid and the vas deferens widens to form a seminal vesicle. The uterus is sac-form. The gravid segments are readily digested or rupture within the intestine and the eggs thus set free usually occur in large numbers in the feces of infected individuals. The eggs are globular, more frequently oval and present two membranes, the outer measures from 40 μ to 60 μ in diameter and the inner from 20 μ to 34 μ. The inner membrane shows filiform projections at each pole (Figure 152).

FIG. 152.—Egg of *Hymenolepis nana.*

FIG. 151.—*Hymenolepis nana*, entire worm. About 12/1. (From Fantham, Stephens, and Theobald, *Animal Parasites of Man.* (After Leuckart)

Life-cycle. No intermediate host is required for the development of *H. nana,* and, as the eggs are immediately infective as they pass out with the feces, it is very likely that autoinfection frequently occurs. Upon ingestion, the onchosphere becomes free in the small intestine and penetrates into a villus where it becomes a cysticercoid (Figure 153). In about ninety hours after ingestion the cysticercoid breaks out of the villus and passes into the lumen and soon fixes itself to

FIG. 153.—Longitudinal section through the intestinal villus of a rat, with the cysticercoid of *Hymenolepis nana.* Magnified. (From Fantham, Stephens and Theobald, *Animal Parasites of Man.* After Grassi and Rovelli)

the intestinal epithelium and develops rapidly into the strobilate worm which is attained in about ten or twelve days, and about thirty days after ingestion its eggs may appear in the feces. The development of *H. nana* may be followed without difficulty in laboratory rats after feeding them the strobilate worms obtained from other infected rats.

Treatment. See page 293.

Prevention. Personal hygiene is essential in combating infections with *H. nana*. In view of the fact that rats and mice may serve as reservoirs for human infection these animals should be destroyed if possible and all food safeguarded from them.

2. HYMENOLEPIS DIMINUTA (Rudolphi, 1819)

Hymenolepis diminuta is one of the commonest of the rat and mouse tapeworms and is occasionally found in man. It was first discovered by Olfers in 1766 in rats of Rio de Janeiro and was later described by Rudolphi in 1819 under the name *Tænia diminuta*. It was described from man by Rudolphi in 1805. About seventy-five human cases of infection with *H. diminuta* have been reported. The majority of these infections occurred in children under three years of age. In all probability it is far more frequent in human beings than is indicated by the reported cases.

Description. The strobilate worm measures from 20 cm. to 60 cm. in length and up to 3.5 mm. in breadth. The strobila consists of from 800 to 1000 proglottids. The scolex is very small, club-shaped and has a small infundibulum at the apex in which there is a rudimentary rostellum. The scolex is unarmed and the four suckers are small. The arrangement of the reproductive organs is similar to that of *H. nana*. The eggs, when present, are found free in the feces of the host. They are round or slightly oval with an outer shell, yellowish, thickened and maybe striated, and an inner shell, colorless, and somewhat pointed at the poles but without filiform projection. The outer shell measures from 54 μ to 86 μ in diameter and the inner membrane or embryophore from 24 μ to 40 μ by 36 μ.

Life-cycle. Unlike *H. nana,* this species of *Hymenolepis* requires an intermediate host for the completion of its life-cycle. Direct infection is not possible. Grassi and Rovelli (1892) showed that the larval stage of *H. diminuta,* the cysticercoid develops in the body cavity of a surprising range of meal-infecting insects. They have been noted in the larva and adult of the moth, *Pyralis farinalis,* and in both nymphs and adults of the earwig, *Anisolapis annulipes,*

and in adults of tenebrionid beetles, *Tenebrio molitor, Akis spinosa* and *Scaurus striatus.* Joyeux (1920) found that the larvæ of *Tenebrio molitor* could not be infected with the eggs of *H. diminuta* but that the adult beetle was most susceptible. The dung beetles, *Geotrupes sylvaticus,* were observed also to be readily infected with these cysticercoids as well as larvæ of the fleas, *Leptopsylla musculi, Pulex irritans* and *Ctenocephalus canus.* Nicoll and Minchin (1911) found the cysticercoid of *H. diminuta* in 4 per cent of rat fleas, *Ceratophyllus fasciatus,* and Johnson (1913) found that the flea *Xenopsylla cheopis* might also harbor this larva. Nickerson (1911) suspecting that myriapods transmitted the infection to man fed segments of *H. diminuta* from rats to young myriapods, *Fontaris virginica* and *Julus* sp. In both species cysticercoids were found upon later examination.

In view of this wide range of intermediate hosts the cosmopolitan distribution of *H. diminuta* can easily be explained. Joyeux (1920), however, regards the adult *Tenebrio molitor* and the rat fleas, *Ceratophyllus fasciatus* and *Xenopsylla cheopis* as the natural intermediate hosts of *H. diminuta.*

When the infected intermediate host is ingested by a susceptible host the cysticercoid becomes free in the intestine of the new host and the scolex fixes itself to the intestinal epithelium. It becomes an adult and eggs appear in the host's feces in about eighteen days. It is believed that man becomes infected most frequently from eating breads not well cooked that contain the infected intermediate host.

Prevention. Prevention against infection with *Hymenolepis diminuta* consists in avoiding the ingestion of any of the various arthropods which may serve as intermediate hosts. Rigid cleanliness should be followed with regard to what is placed in the mouth by keeping food protected from the intermediate host and by the destruction of rats, mice and the arthropods concerned.

Many species of *Hymenolepis* are reported from North American birds. The reader is referred to Ransom (1909) for a list of these species.

3. HYMENOLEPIS LANCEOLATA (Bloch, 1782)

Hymenolepis lanceolata is a common parasite of geese and ducks in Europe and has been reported once from man in Germany.

Description. The external characteristics of this parasite are well marked and its recognition is not difficult. It has a length varying

from 30 mm. to 130 mm. with a posterior maximum width of 18 mm. The strobila gradually increases in width from the scolex backward, reaching its greatest width a short distance anterior to the posterior extremity, then becomes narrower again and rounded off posteriorly, thus producing its characteristic lancet shape. The scolex is very small and possesses a rostellum armed with a single row of hooks, usually eight in number. The genital pores open on the right hand margin of the strobila, near the anterior border of each proglottid. The egg is spherical or slightly oval and possesses an outer and inner membrane, both of which are very thin. The outer membrane measures from 60 μ to 100 μ in diameter and the inner measures 30 μ by 25 μ to 40 μ by 25 μ.

Life-cycle. The eggs of *H. lanceolata,* when deposited in pools by infected ducks or geese, are ingested by fresh-water crustaceans, *Cyclops* or *Diaptomus,* and develop into cysticercoids in the body cavity of these hosts. When the infected crustacean is introduced into the digestive tract of a susceptible host, usually by drinking the water, the cysticercoid develops into the strobilate worm.

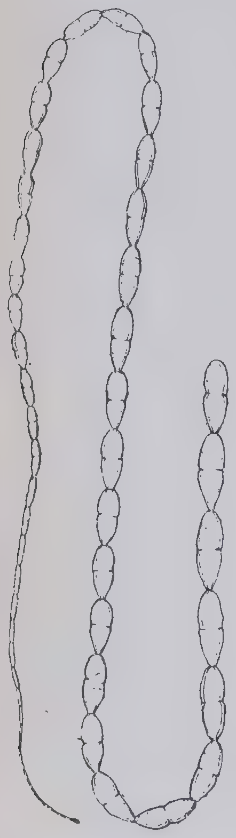


FIG. 154.—*Dipylidium caninum.* Strobilate stage. Natural size (From Brumpt's *Précis de parasitologie*)

V. *Family Dipylidiidæ* Luehe, 1910

The family DIPYLIDIIDÆ is made up of moderate sized tapeworms. The suckers are unarmed but the rostellum is usually armed. The genitalia are single or double and the uterus breaks up into egg-sacs, each containing one or several eggs. There are no paruterine organs. The testes may be numerous. The adults are parasites of mammals and birds.

1. DIPYLIDIUM CANINUM (Linnæus, 1758)

Description. Dipylidium caninum (Figure 154) is one of the commonest intestinal parasites of dogs and cats and is occasionally found as a human parasite. The adult measures from 15 cm. to 40 cm. in length and has a

maximal breadth of from 2 mm. to 3 mm. The scolex is small and rhomboidal, measuring about 0.55 mm. in diameter. The rostellum is claviform and is capable of retraction into a deep cephalic infundibulum. It is armed with three or four circlets of about sixty hooks of rose thorn shape. The hooks of the most anterior row are the larger, from 12 μ to 15 μ long. The hooks are easily lost and specimens are often found without hooks or only a few may still be in place. There are four, fairly large, elliptical, unarmed suckers. The neck is very short and thin. There are usually less than 200 proglottids in the entire chain. The mature or gravid segments are characteristically vase or urn-shaped (Figure 155). Each proglottid has two sets of genital organs and the genital pores lie symmetrically at the lateral margins. The vitellarium is some distance posterior to the ovary and is irregularly and loosely lobulate. The eggs of *D. caninum* are round and measure from 43 μ to 50 μ in diameter. They are contained in nest-like cavities of the uterus, each including from five to twenty eggs. Eggs are seldom seen in the host's feces unless the proglottid becomes disintegrated or broken. Therefore the diagnosis is best made from segments passed with the host's feces.

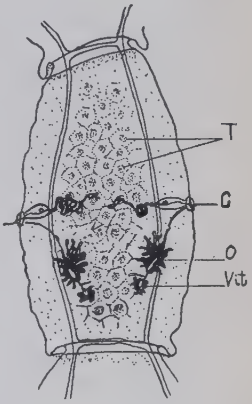


FIG. 155.—Mature segment of *Dipylidium caninum*. Enlarged. (Original)

Life-Cycle. Leuckart believed that an insect intermediate host was necessary for the completion of the life-cycle of *D. caninum* but Melnikoff in 1869 was the first to demonstrate the larval form in the body of such a host, the dog louse, *Trichodectes canis.* In view of the fact that *T. canis* is not a frequent parasite of dogs and cats, it soon became apparent that this louse could not be the only intermediate host for this parasite. In 1880, Grassi found that it could also develop in the dog flea, *Ctenocephalus felis,* and in the human flea, *Pulex irritans.*

As in the case of many tapeworms, the gravid segments of *D. caninum* are carried along with the host's feces to the outer world where they disintegrate and the enclosed onchospheres become scattered about. Some of the onchospheres which eventually get into the fur of the dog or cat are ingested by the louse, *Trichodectes,* as it feeds on the skin of the dog, and in its body cavity they develop into the infective stage. In the case of the fleas, however, the eggs are in-

gested while the fleas are larvæ, feeding on débris. The adult fleas are adapted to feed on blood and are unable to ingest a tapeworm egg. The onchospheres remain more or less unchanged in the adipose tissue and muscles of the flea larva during its various developmental stages until the adult emerges, at which time they develop into pear-shaped bodies within which are the invaginated head and suckers of the future tapeworm. This larva is a cysticercoid.

When the dog or cat takes up an infected flea by biting itself, or by licking its fur, the cysticercoid becomes free in the intestine and after attaching itself to the wall of the intestine quickly grows into the adult worm. Sexual maturity is reached in about twenty days. As many as fifty cysticercoids have been found in the body cavity of a single flea, therefore a rather heavy infection may result from the ingestion of one infected flea.

Infection in man is entirely accidental and is evidently brought about through food contamination or through the practice of allowing dogs to lick the face at which time the flea is ingested. Infection in man, as well as in other definitive hosts, can only be acquired by swallowing the infected adult flea or louse. There are now about eighty records of its occurrence in man. Most of the cases are European. It is exceedingly rare in man in the United States. The majority of the infections have occurred in young children, many of whom were of nursing age.

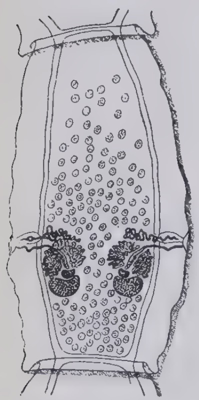


FIG. 156.—*Dipylidium sexcoronatum*. Mature segment. Enlarged. (From Hall. After von Ratz)

2. DIPYLIDIUM SEXCORONATUM von Ratz, 1900

Dipylidium sexcoronatum is a tapeworm of dogs and has been found in Hungary and the United States. While this species appears to be a rare parasite in the United States, Hall (1917) is of the opinion that it may be a very common one, and that its identity has been confused with *D. caninum*. The strobila of *D. sexcoronatum* is much narrower than that of *D. caninum* and the vitellarium is a relatively large and compact reniform structure while in *D. caninum*, this organ is smaller, irregular and loosely lobulate (Figure 156).

The life history of *D. sexcoronatum* is not known but it is probably similar to that of *D. caninum*.

Four other species of *Dipylidium* have been reported from cats: *D. örleyi* von Ratz, 1900, from cats of Hungary; *D. pasqualei* Diamare, 1893, from cats of Egypt; *D. chyzeri* von Ratz, 1897, from cats, probably of Hungary; and *D. trinchesii* Diamare, 1892, from cats of Italy and Egypt.

CHAPTER XXV

THE CLASS NEMATODA

The NEMATODA are easily distinguished from other helminthes by their round, elongated, non-segmented bodies. They are further characterized by having a relatively large body cavity in which the internal organs are suspended. The body cavity, however, is not a true cœlom as in ANNELIDA and higher animals, since a peritoneal epithelium is lacking. It is formed by the simple breaking down of the connective tissue cells, many of which remain as remnants, especially at the anterior end. The NEMATODA therefore show, in this respect, a closer relation to parenchymatous PLATYHELMINTHES than to the ANNELIDA and higher invertebrates having a true cœlom. The sexes are usually separate and show marked sexual dimorphism.

I. *General Characteristics of the Class*

The NEMATODA, or nemas, have characteristically elongated, cylindrical bodies tapering slightly towards one or both ends and, as a rule, present a smooth, glistening external surface. The anterior end of the worm is usually more or less rounded while the posterior end is pointed. There are both free-living and parasitic nematodes. They have become adapted to almost every conceivable habitat. The free-living forms are abundant in soil and water and occur in arid deserts, lake and river bottoms, and thermal springs, as well as in polar seas and at great depths. Cobb (1914) has estimated that the number of nematodes in the top six inches of an acre of ordinary arable soil, may reach thousands of millions. Many species are parasites of plants and are of considerable economic importance, especially in the sugar beet, citrus and cocoanut industries. It is estimated that over 80,000 nematode species infect the forty-odd thousand species of vertebrates. Insects are also often infected by nematodes as well as molluscs, annelids and crustaceans. Morphologically the parasitic species are strikingly similar to the free-living forms and show but minor modifications resulting from their parasitic habit. This is especially true among the smaller transparent species.

The main points of difference between the free-living and parasitic species lie in the presence of eye-spots, setose tactile organs, æmphids and other specialized sensory organs in the free-living forms, and their usual absence in the parasitic ones. When present among the parasitic forms, these sensory organs occur in the free-living developmental stages of the worm and not in the parasitic adult.

Nematodes range from a fraction of a millimeter to more than a meter in length and are usually white or nearly colorless. The male is usually smaller than the female and is readily distinguished by a recurved posterior extremity, or, in certain species, by special copulatory apparatus such as spicules and bursæ at the posterior extremity.

I. MUSCULAR SYSTEM

The body of nematodes is covered with a hyaline, non-cellular layer, the cuticula, which is composed of proteins of albuminoid character, and bears transverse striations which often are exceedingly fine. Directly beneath the cuticula lies the subcuticula or hypoderm which forms the cuticula. Within the hypoderm lies a single layer of partially differentiated longitudinal muscles which line the body cavity. Each muscle cell has only a portion of the protoplasm differentiated into contractile fibers and these fibers lie next to the hypoderm. The rounded, undifferentiated portion containing the nucleus usually extends into the body cavity. This muscle layer together with the cuticula and hypoderm constitute what is termed the dermo-muscular tube. The dermo-muscular tube is frequently divided into four equal quadrants by the thickening of the hypoderm along the center of both lateral and dorsal and ventral surfaces. The thickenings along the lateral surfaces are known as the "lateral lines" within which ~~the~~ lateral ducts of the excretory system are carried. These lines are relatively large and in the larger species can be detected under the cuticula with the unaided eye. The mid-dorsal and mid-ventral lines are less conspicuous and carry the two main longitudinal nerve trunks.

The character and arrangement of the muscles of the dermo-muscular tube, as seen in cross section, form a characteristic by which one can identify certain groups of nematodes. Those species in which the muscle cells are numerous and extend well into the body cavity are spoken of as polymyarian (Figure 157, a). The ASCARIDÆ, HETERAKIDÆ and the like are polymyarian. In other species the muscle cells are flattened and only from two to three occur in each

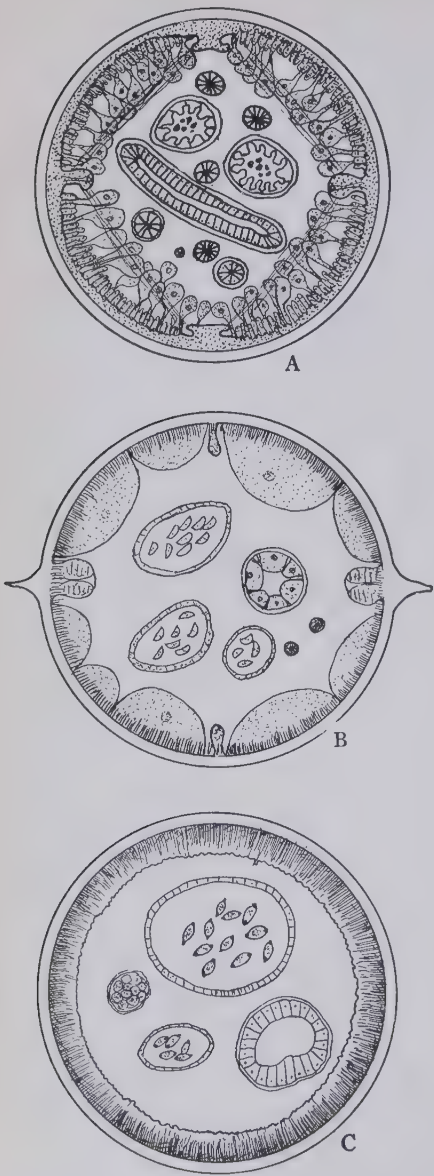


FIG. 157.—Musculature of Nematodes. A, polymyarian type; B, meromyarian type; C, holomyarian type.

lateral field; these are known as meromyarian. This grouping of muscle cells is characteristic of the OXYURIDÆ (Figure 157, b). In the third type, holomyarian, the muscle cells are small and closely packed together and usually form a complete wall within the cuticular layer. This type is characteristic of the TRICHINELLINÆ to which belongs *Trichuris trichiura,* the common whip-worm of man (Figure 157, c).

2. DIGESTIVE SYSTEM

The digestive system of the nematodes is very simple and consists practically of a straight tube running from the mouth at the anterior tip to the anus on the ventral surface at a short distance above the posterior extremity (Figure 158). The mouth is usually surrounded by lips or papillæ and in some species it bears teeth for grasping and tearing loose the host's tissues. The mouth cavity may be simply tubular or funnel-shaped while in some species it is expanded into a cup-shaped capsule which serves as a sucking organ. Behind the mouth cavity there usually occurs a muscular or capillary esophagus. The muscular type shows in cross section a triradial lu-

men lined with a heavy cuticula with the muscle fibers perpendicular to the lumen. By contraction, these fibers widen the lumen and the esophagus thereby functions as a pump to draw in food. The heavy cuticular lining is their antagonist. The esophagus usually terminates in a more or less conspicuous bulb or valvular apparatus. Glandular elements are embedded in the muscular wall of the esophagus. The capillary type of esophagus consists of a small, thick-walled tube which passes straight into the intestine through a row of granular cells without well-developed muscular elements. The intestine continues posteriorly as a more or less flattened tube with a relatively large lumen. Its wall is composed of columnar epithelium with the cells rich in protoplasm. In the female worm, the intestine narrows into a rectum which is lined by cuticula. In the male worm, however, the genital duct opens into the posterior region of the intestine thus forming a common passageway, the cloaca.

3. EXCRETORY SYSTEM

The excretory system consists of one long cylindrical cavity commencing in the posterior extremity of each lateral line. These cavities pass forward to unite near the anterior extremity of the body and communicate with the exterior through a single excretory pore which is located in the mid-ventral line near the middle of the esophagus.

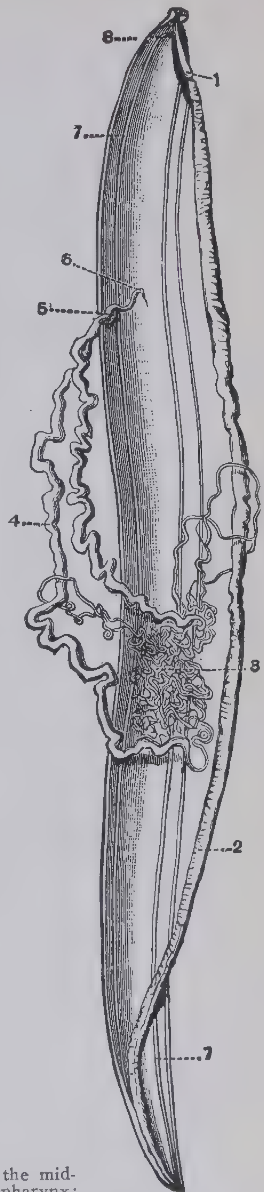


FIG. 158.—A female *Ascaris lumbricoides* cut open along the mid-dorsal line to show typical internal organs of nematodes. 1, pharynx; 2, intestine; 3, ovary; 4, uterus; 5, vagina; 6, vulva; 7, excretory tube; 8, excretory pore. (From Shipley and MacBride)

4. NERVOUS SYSTEM

A ring of nervous tissue surrounds the esophagus from which two main nerve trunks pass posteriorly within the dorsal and ventral lines. A number of smaller strands are also given off from the nerve ring, some extending forward and others a short distance backward. Our knowledge of the nervous systems of nematodes is limited to a comparatively few species.

5. REPRODUCTIVE SYSTEM

The reproductive system of both sexes in NEMATODA is an exceedingly simple, long, tubular structure in which the various organs are continuous and only slightly differentiated from each other in external appearance (Figure 158). The male reproductive organs are single and occupy the posterior third of the body. The testis is terminal, coiled and thread-like and leads through a vas deferens into a dilated portion, the seminal vesicle. The seminal vesicle is followed by a muscular ejaculatory duct of varying lengths which opens into the cloaca. Spicules which serve as organs of copulation are usually present in connection with the terminal portion of the male system and are withheld in pouches in the immediate vicinity of the ejaculatory duct. In many species, the males are equipped with wing-like appendages, a copulatory bursa at the posterior extremity, and cement glands, the secretions of which serve for copulation. The spermatozoa are rounded bodies capable of ameboid motion and in some species are not formed in the male, but develop in the female from the sperm mother cells which are transferred to her during copulation.

FIG. 159.—*Ascaris lumbricoides.* Germinal zone of ovary. (After Cram)

The female reproductive system may be either a single or a bifurcated tube, although most frequently it is bifurcated. The vulva is a small opening on the ventral surface and usually appears as a

simple transverse slit. In *Ascaris suum,* a common intestinal parasite of swine, and a type easily obtained for study, the vulva is situated about one-third the distance from the anterior end of the body and leads into a short muscular vagina from which two uteri branch off and follow a fairly straight parallel course backward to the posterior portion of the worm where each uterus turns forward. At this end of the uterus is situated the seminal receptacle, beyond which is the oviduct and then the terminal thread-like ovary which coils back and forth to such an extent that a cross section of the worm shows from twenty to thirty sections of the ovaries.

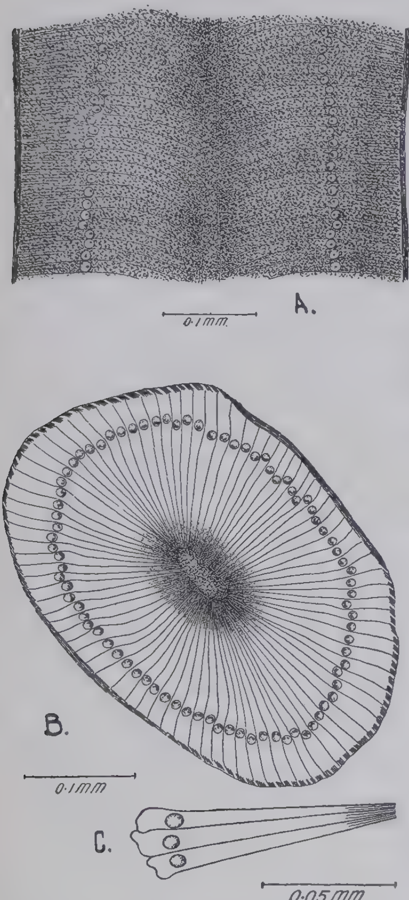


Fig. 160.—*Ascaris lumbricoides.* A., longitudinal section of ovary; B., cross section of ovary; C., ova from ovary. (After Cram)

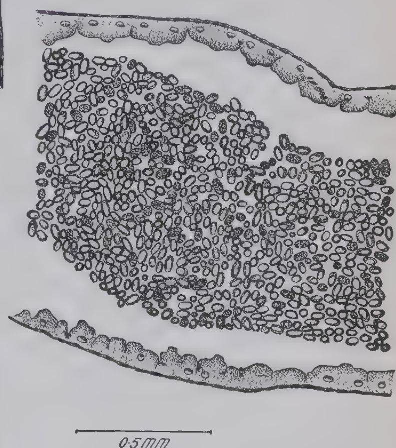


Fig. 161.—*Ascaris lumbricoides.* Longitudinal section of uterus. (After Cram)

Each ovary is from five to eight times the total length of the worm itself. The free or distal portion of the ovary is the germinal zone and contains a mass of protoplasm with an abundance of nuclei, or germinal vesicles, scattered through it (Figure 159). A short distance from the germinal zone the protoplasm is formed around the vesicle

and distinct cells or ova begin to appear. This portion of the ovary is followed by a developmental zone in which the ova have become elongated and are arranged in wreaths around a central stalk or rachis which supplies them with nutriment (Figure 160). Further down, the rachis disappears as the ovary changes to form the oviduct and the ova separate from each other and assume a more or less oval form and produce yolk material within their cytoplasm. They are fertilized in the seminal receptacle after which they produce the shell while in the posterior end of the uterus. In *Ascaris* an albuminous substance is secreted from the walls of the uterus which is superimposed upon the shell as the egg passes along its length (Figure 161).

6. DEVELOPMENT

The development of the parasitic nematodes is exceedingly variable, and although certain species require intermediate hosts, their life-cycles are never as complicated as those of the digenetic trematodes. The nematodes, like all other helminthes, do not multiply within the body of their hosts. Each adult present is the result of a successful entrance and development of a single infective organism. Multiplication within the host has been attributed to *Strongyloides stercoralis* (Thira, 1919) and *Enterobius vermicularis,* but experimental evidence is lacking on this point. A few parasitic nematodes, however, possess multiplicative periods outside of the definitive host, and these, when present, occur in the free-living generations, as in the genera *Rhabdias* and *Strongyloides* of the family RHABDIASIDÆ.

The eggs of parasitic nematodes may be discharged either before or during segmentation, or with the embryo fully developed. In a few species the embryos hatch within the uterus of the female worm and are then brought forth viviparously. The embryonic development is simple and much alike in all species. The larvæ upon hatching have the main characteristics of nematodes but are not sexually developed. Many parasitic species have certain adaptive larval characters which are subsequently lost. In the course of its development, the worm undergoes about four moults with the adult stage following after the fourth or last moult. Among the parasitic species some of these moults may take place within the egg before hatching, during its free existence, while within the tissue of an intermediate host, or within the tissues of the definitive host.

II. *Parasitism among the Nematodes*

Many nematodes appear to be facultative parasites and may live either free or parasitic as opportunities are offered. Several species of the genus *Rhabditis* live abundantly in decaying organic material in the soil and have been reported frequently as parasites of man. To what extent they may become successful parasites is questionable as many of the reported infections appear to have been diagnosed on contaminated waste products of the host.

A number of species parasitic in man and other vertebrates pass through a free-living generation, sexually differentiated into males and females, which alternates with a parasitic parthenogenetic or hermaphroditic generation. In the life-cycle of *Strongyloides stercoralis,* the larvæ produced by the parasitic generation may develop into free-living adult males and females. The free-living female, after copulation, produces eggs. The larvæ which hatch from these eggs feed upon inorganic débris and later metamorphose into non-feeding larvæ, the infective stage. These larvæ when introduced into man or susceptible animals, grow into the adult parasitic generation. *Rhabdias fuscovenosa* from the lung of the grass snake and *Rhabdias bufonis* a common parasite in the lungs of frogs pass through similar stages in their development. These forms are of considerable interest in that they show a close relationship in their free-living generations to *Rhabditis* and certain other non-parasitic nematodes, which suggest possible ancestors from which the parasitic species may have evolved.

Most parasitic nematodes are parasitic in but a single host. Their life-cycles are more or less direct with some stage of development free. They differ, in the various species, mainly in the degree of development attained either before or during the free existence. The hookworms and their close relatives have the embryonic development and the first and second larval stages in the open with the larvæ as feeding stages. The second larva is the end product of the free life and is the infective stage for new hosts. Entrance in the new host is gained by the infective larva boring through the tissues of the host or by food contamination. The life-cycle of *Dictyocaulus filaria,* a parasite of sheep and goats, is somewhat similar to that of the hookworms except that the first and second larvæ, although free, are not feeding stages. These larvæ live on food stored up in the intestinal cells during embryonal development. The post embryonic development up to the first moult is passed inside the eggs of *Ostertagia marshalli.* Its second larva is free but, like that of *Dictyocaulus,*

is not a feeding stage. The first and second larval stages of *Nematodirus filicollis* of sheep and cattle and *Oswaldocruzia auricularis* from the frog are passed within the egg and when the larva emerges from its shell it is already in the infective stage.

Many nematodes have no development beyond the formation of the embryo outside of the host. The egg alone is free. The eggs of *Ascaris lumbricoides* and *Trichuris trichiura* leave the host in an unsegmented condition and a relatively long period in the open is required before the embryo is formed. The embryonated egg is the end product of the free life for these parasites and is the infective stage for other hosts. When it is ingested by a susceptible host it hatches in the alimentary tract of the host and after a series of moults the adult stage is reached. In other species, such as *Enterobius vermicularis* from man, and *Trichosomoides crassicauda* from rats, the embryonic development is completed in the body of the host and when the eggs are passed into the outer world they are immediately infective.

Some nematode species are parasitic in both adult and larval stages and require an intermediate host or a change of hosts to complete their life-cycle. Among these nematodes, certain species have some stage which is free. The guinea worm, *Dracunculus medinensis,* has its first larval stage in the open. The female is viviparous and lives in the connective tissue underneath the epidermis of the host. Her young are expelled into water, whenever such an opportunity is offered, and are ingested by certain fresh-water crustaceans (*Cyclops*). Within the body cavity of the *Cyclops* further moults occur after which they become infective larvæ. Further development can take place only after the infected *Cyclops* is ingested by man. *Gongylonema scutatum,* a parasite of horses, sheep and cattle, is free only in its egg stage. The egg of this nematode already contains a fully developed embryo when it leaves the body of the definitive host. When it is ingested by certain coprophagous beetles it hatches in the digestive tract and later becomes an infective larva encysted in the body cavity. To complete its development, it must reach its vertebrate host. This is accomplished when the vertebrate host accidentally ingests the infected beetle with other food.

Certain other species requiring a change of host have no stage which is free. The FILARIIDÆ are parasites in the connective or lymphatic tissues. The females are viviparous, and as her young circulate in the peripheral blood they are taken up by certain blood-sucking insects within the bodies of which the larvæ undergo a metamorphosis after which the infective stage is reached. The infection is returned to

the vertebrate host when the insect feeds upon that host. In the case of the trichina worm, *Trichinella spiralis,* both adult and larval stages develop within ~~the same host~~. The sexually mature worms inhabit the small intestine. The gravid female is viviparous and deposits her young directly into the circulating blood and lymph. They are carried by the blood to the musculature where they encyst. Within the cyst the larvæ grow and later show sexual differentiation into males and females. The multiplicative period of these forms, however, is only reached after the muscle containing them is eaten by another susceptible host, at which time they are freed from their cysts in the alimentary tract and the cycle is recommenced.

III. *Classification*

The student is referred to Yorke and Maplestone (1926), Stiles and Hassall (1926) and Baylis and Daubney (1926) for detailed classification of Nematoda. Table VII gives a general classification after Baylis and Daubney (1926) of nematodes of particular medical importance.

Table VII

DISTRIBUTION, INCIDENCE AND DIAGNOSIS OF THE COMMONER AND MORE IMPORTANT NEMATODES

Order	*Scientific Name*	*Organ Inhabited*	*Development*	*Geographical Distribution*	*Incidence*	*Diagnosis*
ASCAROIDEA	*Ascaris lumbricoides*	Small intestine of man	Direct—egg only free	Cosmopolitan	Frequent	Eggs in feces
	Ascaris suum	Small intestine of pig	Direct—egg only free	Cosmopolitan	Frequent	Eggs in feces
	Enterobius vermicularis	Upper part of large intestine of man	Direct—egg only free	Cosmopolitan	Frequent	Adult worms on feces, in bed-clothing, eggs in scrapings from finger-nails, etc.
	Heterakis gallinæ	Small intestine of fowl	Direct—egg only free	Cosmopolitan	Frequent	Eggs in feces
	Oxyuris equi	Large intestine of horse	Direct—egg only free	Apparently cosmopolitan	Frequent	Presence of worms on feces and anal regions
	Rhabdias bufonis	Lung of frog	Heterogenetic, alternating parasitic and free-living generations	Apparently cosmopolitan	Frequent	
	Strongyloides stercoralis	Small intestine of man, dog and cat	Heterogenetic, alternating parasitic and free-living generations	In tropical and subtropical countries	Frequent	Rhabditiform larvæ in fresh feces or filariform (infective larvæ) from cultures
	Syphacia obvelata	Small intestine of mice and man	Apparently direct—egg only free	Apparently cosmopolitan in mice	Frequent in mice, rare in man	Adult worms and eggs in feces
	Toxascaris cati	Small intestine of cat	Direct—egg only free	Cosmopolitan	Frequent	Eggs in feces, worms in vomitus
	Toxocara canis	Small intestine of dog	Direct—egg only free	Cosmopolitan	Frequent	Eggs in feces, worms in vomitus

DISTRIBUTION, INCIDENCE AND DIAGNOSIS OF THE COMMONER AND MORE IMPORTANT NEMATODES—(*Continued*)

STRONGYLOIDEA	*Ancylostoma caninum*	Small intestine of dogs and cats	Direct, with larval development in open	Cosmopolitan	Frequent in warmer countries, fairly frequent in kennels	Ova in feces
	Ancylostoma duodenale	Small intestine of man	Direct, with larval development in open	In tropical and subtropical countries	Frequent in mines of Western U. S.	Eggs in feces
	Bunostomum trigonocephalum	Small intestine of sheep	Direct, with larval development in open	Europe and United States	Frequent in Southern U. S.	Eggs in feces
	Dictyocaulus filaria	Bronchi and bronchioles of sheep, goats and cattle, etc.	Direct, with larval development in open	World-wide	Comparatively common in U. S., especially in South	Larvæ in saliva from back of tongue
	Hæmonchus contortus	Fourth stomach of sheep, small intestine of man	Direct, with larval development in open	World-wide	Frequent in sheep, very rare in man	Eggs in feces
	Metastrongylus apri	Bronchi of pigs and man	Direct, with larval development in open	World-wide	Fairly common in pigs, rare in man	Larvæ in discharges from trachea
	Nematodirus filicollis	Small intestine of sheep and cattle	Direct, with larval development within egg in open	North America, Europe, New Zealand and Australia	Common in United States	Eggs in feces
	Necator americanus	Small intestine of man	Direct, with larval development in open	In tropical and subtropical countries	Frequent in Southern U. S.	Eggs in feces
	Œsophagostomum columbianum	Cecum and large intestine of sheep and goats	Apparently direct, details not known	Especially prevalent in warmer countries	Frequent	Eggs in feces

DISTRIBUTION, INCIDENCE AND DIAGNOSIS OF THE COMMONER AND MORE IMPORTANT NEMATODES—(*Continued*)

Order	*Scientific Name*	*Organ Inhabited*	*Development*	*Geographical Distribution*	*Incidence*	*Diagnosis*
STRONGYLOIDEA—*continued*	*Stephanurus dentatus*	Fatty tissue surrounding kidneys of pig	Apparently direct, details not known	Southern U. S., Central and South America	Frequent	Post-mortem
	Strongylus vulgaris	Cecum and large intestine of EQUIDÆ	Direct, with larval development in open	Especially prevalent in warmer countries	Frequent	Eggs in feces
	Syngamus trachea	Trachea and bronchi of domestic and wild birds	Direct, with larval development in open	United States, Europe and Brazil	Frequent	Characteristic eggs in mouth discharges or feces. Worms in trachea
	Trichostrongylus capricola	Fourth stomach of sheep	Probably direct, with larval development in open	North America and Europe	Most frequent species of Trichostrongylus in sheep in U. S.	Eggs in feces
	Trichostrongylus orientalis	Small intestine of man	Probably direct, with larval development in open	Japan, Korea	Frequent	Eggs in feces
FILARIOIDEA	*Acanthocheilonema perstans*	Connective tissue and deeper fat about mesentery and abdominal aorta of man	Indirect, larval development probably in mosquitoes	Tropical West Africa	Frequent among natives	Microfilaria in blood
	Cheilospirura hamulosa	Gizzard of fowl	Indirect, larval development probably in arthropods, perhaps insects	World-wide	Frequent	Eggs in feces
	Dirofilaria immitis	Right ventricle and blood stream of dog	Indirect, larval development in mosquitoes, *Anopheles maculipennis, Ædes calopus*	World-wide	Frequent in China and Japan, occurs also in U. S.	Microfilaria in blood
	Dispharynx nasuta	Connective tissue of proventriculus, gizzard of fowl	Indirect, larval development in sow-bug	World-wide	Frequent	Eggs in feces

DISTRIBUTION, INCIDENCE AND DIAGNOSIS OF THE COMMONER AND MORE IMPORTANT NEMATODES—(*Continued*)

FILARIOIDEA—*continued*

Dracunculus medinensis	Subcutaneous tissue of man and other mammals	Indirect, larval development in *Cyclops*	India, Africa, Arabia, Near East, Brazil	Frequent locally	Adult worm in subcutaneous tissue
Filaria ozzardi	Mesentery and visceral fat of man	Indirect, larval development unknown	West Indies and northern South America	Not definitely known	Microfilaria in blood
Gnathostomum spinigerum	Intestine of cats, larvæ in subcutaneous tissue of man	Unknown	Far East	Accidental and rare in man	Eggs in feces of normal host
Gongylonema scutatum	Mucosa of esophagus of sheep, etc.	Indirect, larval development in dung beetles	Apparently worldwide	Frequent in southern U. S.	Eggs in feces
Habronema megastoma	In ulcers of stomach of horse, etc.	Indirect, larval development in maggots and adult house-flies	Apparently worldwide	Frequent in southern U. S.	Larvæ in feces and "summer sores"
Loa loa	Subcutaneous, connective tissue of man	Indirect, larval development in mangrove flies, *Chrysops dimidiatus* and *C. silaceus*	Indigenous in tropical West Africa only	Frequent among natives of Africa and occasionally in Europeans and Americans returned from West Africa	Microfilaria in blood, or presence of adult worms in subcutaneous tissue
Onchocerca cæcutiens	Subcutaneous, connective tissue, especially about face, man	Indirect, larval development probably in *Simulium*	Central America	Relatively frequent at higher altitudes of Guatemala	Characteristic lesions with microfilaria or adult worms
Onchocerca volvulus	Subcutaneous, connective tissue of man	Indirect, probably larval development in *Simulium damnosum*	Tropical West Africa	Frequent among natives	Microfilaria in skin of waist region
Wuchereria bancrofti	Lymphatics of trunk and extremities of man	Indirect, larval development in mosquitoes, *Culex fatigans*, *Ædes variegatus*	Wide tropical and subtropical distribution	Endemic in Charleston, S. C.	Microfilaria in blood

DISTRIBUTION, INCIDENCE AND DIAGNOSIS OF THE COMMONER AND MORE IMPORTANT NEMATODES—(*Continued*)

Order	*Scientific Name*	*Organ Inhabited*	*Development*	*Geographical Distribution*	*Incidence*	*Diagnosis*
DIOCTOPHYMOIDEA	*Dioctophyme renale*	Kidney of dog and other mammals	Indirect, larval development probably in fish	World-wide	Frequent locally	Eggs in urine
TRICHINELLOIDEA	*Hepaticola hepatica*	Liver of rat and man	Direct—eggs only free	World-wide	Rare in man	
	Trichinella spiralis	Adults in intestine, larvæ in musculature of same host—man, rat, pig, etc.	Requires change of host	World-wide	Frequent in rats and hog, locally frequent in man	Larvæ in blood or muscles
	Trichuris trichiura	Cecum of man	Direct—eggs only free	World-wide	Especially frequent in warmer countries	Eggs in feces
	Trichuris vulpes	Cecum of dog, etc.	Direct—eggs only free	World-wide	Frequent in kennels	Eggs in feces
		ACANTHOCEPHALA				
	Macracanthorhynchus hirudinaceus	Intestine of pig	Indirect, larval development in dung beetles	World-wide	Frequent	Embryos in feces

CHAPTER XXVI

THE ORDER ASCAROIDEA

The order ASCAROIDEA consists of both free-living and parasitic nematodes having normally three lips, of which one is dorsal and two are subventral. In certain genera the lips may be much reduced or absent.

Baylis and Daubney (1926) have divided the order ASCAROIDEA into fourteen different families of which four are of particular interest in medical zoölogy. They include the ASCARIDÆ Cobbold, 1864, HETERAKIDÆ Railliet and Henry, 1914, OXYURIDÆ Cobbold, 1864, and the RHABDITIDÆ Micoletzky, 1922.

I. *Family Ascaridæ* Cobbold, 1864

The ASCARIDÆ are parasitic forms, polymyarian, with lips well developed, bearing papillæ and sometimes alternating with three interlabia. There is no buccal cavity. The reproductive organs are highly developed. The male has two spicules and in some species an accessory piece, a gubernaculum, is present. The uterine branches of the female are parallel. Eggs are very numerous and contain an unsegmented ovum when deposited.

I. ASCARIS LUMBRICOIDES Linnæus, 1758

Description. Ascaris lumbricoides (Figure 162) is the common roundworm of man. In the living condition it may be milk-white or somewhat reddish-yellow in color and has a characteristic sheen. It is the largest of the human intestinal nematodes. The females usually vary from 20 cm. to 25 cm. but may attain even greater lengths with a diameter of about 5 mm. The males are smaller and measure from 15 cm. to 17 cm. by 3 mm. in diameter. The cuticula is smooth and rather plainly marked by numerous fine striations. The lips are finely toothed (Figure 163). The dorsal lip carries two sensory papillæ and each of the two ventral lips has one sensory papilla. The anus is subterminal. The posterior end of the male is usually somewhat recurved and bears

numerous ventral preanal and postanal papillæ and two short, but prominent, spicules. The vulva is anterior to the middle of the body near the junction of the anterior and middle thirds. The eggs are oval with a thick, transparent shell surrounded by an external albuminous coating which is coarsely mammillated. The eggs

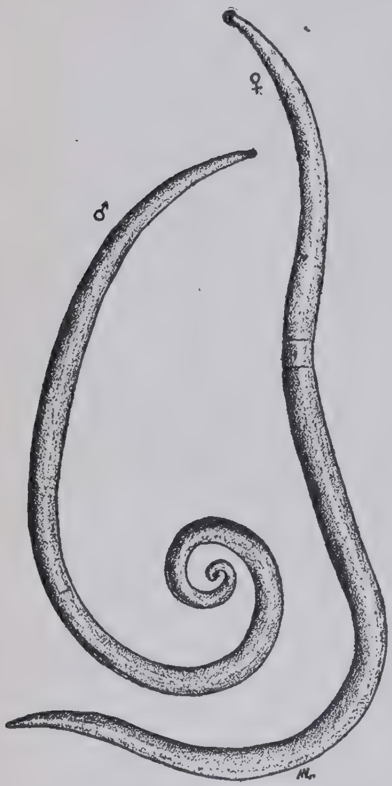


FIG. 162.—*Ascaris lumbricoides*, adult male and female worms, about 2/3 natural size. (From Neveu-Lemaire's *Parasitologie des Animaux Domestiques*, J. Lamarre, Paris)

FIG. 163.—*Ascaris lumbricoides*. Head, end-on view (x 56). (Redrawn from Yorke and Maplestone)

measure from 50 μ to 75 μ in length by 40 μ to 50 μ in breadth, and are unsegmented at the time of deposition (Figure 165). They are colorless when they leave the uterus of the female but during their short stay in the intestinal tract of the host the albuminous layer acquires a yellowish or deep brown color from the bile. Occasionally eggs are passed without the albuminous coating and frequently unfertilized and atypical fertilized eggs are found. *Ascaris lumbricoides* is known to produce an enormous number of eggs. Cram (1925) estimated that the number of eggs in a single female may be as high as 27,000,000; and Brown and Cort (1927) and Augustine and others (1928) calculated that the number of *Ascaris* eggs per gram of feces passed by an infected person may average over 2,000 per female worm.

Ascaris lumbricoides was thought for many years to be the same ascarid which is common in swine, *Ascaris suum* Goeze, 1872, since both were found to be morphologically, toxicologically and serologi-

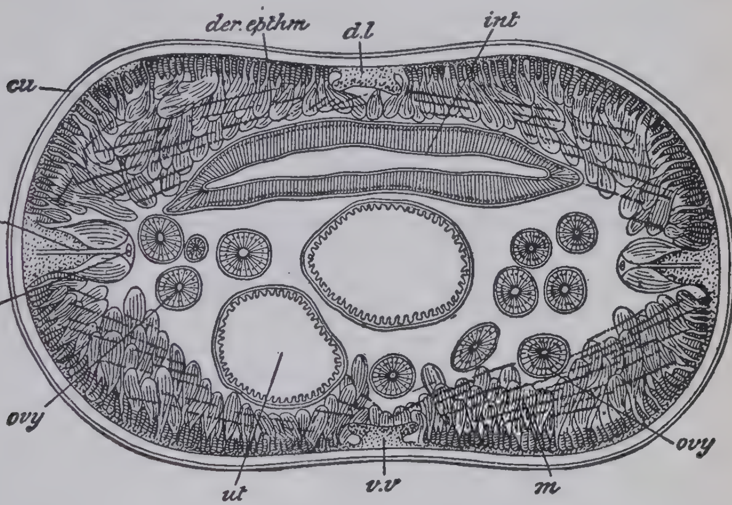


FIG. 164.—Cross section of female *Ascaris lumbricoides*. *cu*, cuticula; *d.l*, dorsal line; *der. epthm*, epidermis; *ex.v*, excretory tube; *int*, intestine; *lat.l*, lateral line; *m*, muscular layer; *ovy*, ovary; *ut*, uterus; *v.v*, ventral line. (From Hegner. After Vogt and Yung)

cally identical. Recent investigations by Koino (1922), Payne, Ackert and Hartman (1925) and the Caldwells (1926) have shown, however, that the infective eggs of the human *Ascaris* probably do not produce mature ascarids in pigs, and that infective eggs of the pig *Ascaris* probably do not produce mature ascarids in man. It is therefore apparent that these two forms are physiologically distinct and should be regarded as separate species.

FIG. 165.—*Ascaris lumbricoides*. Egg (x 500). (Redrawn from Yorke and Maplestone)

Geographical Distribution. Ascaris lumbricoides is a cosmopolitan parasite of man being distributed throughout all countries of the world. It is, however, most frequent in tropical and subtropical countries where all factors concerned are particularly favorable for its dissemination and development.

Life-Cycle. The eggs of *A. lumbricoides* are unsegmented when they leave the body of the host and under favorable conditions the

embryo is formed in about two weeks (Brown, 1927). Under natural conditions the development of the embryo may take place in water or soil, or wherever the pollution is spread. As the eggs are thick shelled they are extremely resistant, and although they may be deposited in environments unfavorable for development they may remain viable for considerable periods. Davaine (1863) kept embryonated eggs alive for five years and Epstein (1892) was able to produce infections with eggs that had been kept in a culture of feces for a year. Stiles and Gardner (1910) found *Ascaris* eggs viable after 156 days in fecal material which had become quite dry during that time. They have also been found viable after being in the soil of our Southern States over winter (Martin, 1922). Because of their great longevity the soil exposed to continual pollution may become exceedingly heavily laden with living *Ascaris* eggs within the course of time.

Infection with *Ascaris* results from ingesting eggs containing fully developed embryos. The eggs are usually carried to the mouth either with food or water or by accidental transfer of soil containing such ova. They do not regularly hatch in the stomach but pass to the small intestine where they begin to hatch within a few hours after ingestion. The hatching of *Ascaris* eggs may be observed in most laboratory animals as well as the development which immediately follows. These animals are, however, abnormal hosts and the worms are eliminated before they reach sexual maturity.

Formerly it was believed that the larvæ upon hatching settled down in the small intestine and there developed directly into the adult stage. Recent investigations by Stewart (1916), Yoshida (1919), Ransom, Foster and Cram (1920), Fülleborn (1920-1925) and others, have shown, however, that the larvæ of this parasite, as well as those of certain other ascarids, leave the intestine immediately after hatching and then follow a definite path of migration through the tissues of the host, after which they return to the intestine and grow into mature worms.

The newly hatched larvæ burrow into the wall of the intestine and enter the lymphatic vessels or the venules. If the larvæ enter the lymphatics they are carried to the mesenteric lymph nodes and from there may reach the circulation either by entering the blood capillaries and passing into the portal circulation, or pass into the thoracic duct and from there to the right side of the heart. If the portal circulation is entered the larvæ are carried to the liver where they pass from the interlobular veins to the intralobular veins. From the liver they are carried to the right side of the heart and then to the lungs. Within the lungs they break into the alveoli where some further development

and growth takes place, after which they pass on to the intestine by way of the trachea, esophagus and stomach. This journey through the host's tissues requires about ten days. They become mature worms in the intestine in about two and one-half months.

Pathogenesis. The pathological effects from infection with *Ascaris lumbricoides* may be quite variable, due in part to the fact that the larval stages have an extensive course of migration in the body, and in part to the fact that the adult worms also frequently migrate from the intestine into other organs and tissues. In breaking through from the capillaries into the alveoli of the lungs the larvæ produce small hemorrhages which may result in so severe an inflammation that an extensive or generalized pneumonia is likely to occur, especially if the number of worms is large. Such effects have been frequently produced in laboratory animals and the condition known as "thumps," which occurs naturally in young pigs, is a pulmonary infection with *Ascaris* larvæ. Pulmonary symptoms following the experimental administration of *Ascaris* eggs to man have been described by Koino of Japan and others. Koino (1922) swallowed about 2000 embryonated ova of *Ascaris lumbricoides* and his brother 400 to 500 embryonated ova of *Ascaris suum*. In both the symptoms were similar but were much more severe in the first case. Pronounced pulmonary symptoms with blood in the sputum, headache, fever and muscular pains marked the course of the infection. After medication 667 worms were expelled from the former case but none were obtained from the latter subject.

In light infections with the adult worm there is apparently but little if any damage to the host and in many cases their presence is unsuspected. When occurring in large numbers they may cause intestinal obstruction by an actual mechanical occlusion. Cases of intussusception due to irritation from ascarids have been observed, some of which have required surgical interference. Adult ascarids frequently leave the intestine, especially during febrile disturbances, and wander up the digestive tract and enter the esophagus, nose, ear or the frontal sinus. They are frequently found in the appendix and in the bile ducts where their presence may be followed by abscesses. They may penetrate through the intestinal wall causing peritonitis and have occasionally invaded the genito-urinary tract causing retention of urine and abscesses in the infected tissue.

Nervous and other constitutional symptoms are often the result of intoxication from substances given off by ascarids. Shimanura and Fujii (1917) separated a highly toxic fraction from the body fluid of several different species of *Ascaris* which produced symptoms,

anatomical changes and resistance similar to anaphylactic shock, and Schwartz (1921) isolated a hemolysis and a hemagglutinin from *A. lumbricoides*. Many individuals are very sensitive to contact with *Ascaris*, particularly with the body fluid. Among the symptoms in susceptible persons are irritation of the eyes, nose, throat, edema of the eyes, sneezing, urticaria, lassitude and even prostration. Susceptibility to *Ascaris* toxins is a very common condition among biologists who have been much exposed to contact with the parasite and occasionally may be observed among students during laboratory studies on these parasites.

Treatment. Oil of chenopodium, or its most active anthelmintic constituent, ascaridol, is apparently the most effective drug in removing ascarids. Generally 1 c.c. is effective for adult persons. This drug is decidedly irritating, constipating and toxic, and special contraindications include gastroenteritis, pronounced weakness, gastric stasis and constipation. Purgation is essential. Castor oil in adequate amounts, about one ounce, administered with the drug is protective. If the purgative is not given until two or three hours after administration of the chenopodium, a fast-acting purgative, such as salts, should be given rather than the castor oil (Hall, 1923). Santonin, calomel and thymol have been used to remove ascarids but are less effective than chenopodium.

Prevention. Water from questionable sources should be boiled for drinking purposes and green vegetables and fruits from gardens fertilized with human excreta avoided. Sanitation, sewer systems in cities and towns, and sanitary privies on farms, together with personal habits of cleanliness, are effective preventive measures against *Ascaris* infection in man.

Ascaris maritima has been reported from a child in Greenland and *A. texana* from a man in Texas. These forms have been observed but once and their taxonomic position is doubtful.

2. ASCARIS SUUM Goeze, 1872

Ascaris suum is one of the commonest parasites of pigs and is morphologically similar to the human species, *A. lumbricoides*, but matures only in swine. Because of the frequency with which it is found in pigs it can readily be obtained for morphological and life history studies. This parasite is of great economic importance in hog raising countries. Young pigs are especially susceptible to infection and these often die of pneumonia or "thumps" caused by the larval

ascarids in the lungs. It has been estimated that from 10 per cent to 20 per cent of the pig crop in certain sections of the United States was destroyed each year by "thumps" or pulmonary ascariasis before control measures were inaugurated. Other losses occur in the stunting of growth due to early infections with these worms resulting in a loss in quantity and quality of pork production.

The control of ascariasis in pigs is a relatively simple matter in view of the fact that it is only the very young pigs that are most susceptible to the infection and that an age immunity is established within a few months. It has been recommended (Ransom, 1921) that the sow and the farrowing pen be thoroughly cleaned shortly before farrowing and that the sow and the young pigs be removed within ten days after birth to clean legume pastures or fields previously sown to other suitable forage crops. The pigs are to be kept there, away from permanent hog lots, for at least four months, during which time they have become relatively immuned against infections with *Ascaris*. The putting into practice of this simple system has prevented serious losses from ascariasis in the swine industry of the United States.

3. ASCARIS VITULORUM Goeze, 1782

Ascaris vitulorum is a fairly common parasite of young calves in parts of South Europe, Japan and Ceylon. It has also been found in calves of Antigua and Cuba. The migrations within the body of the host are similar to the course followed by *A. lumbricoides and A. suum.*

Ascarids are rarely found in sheep. *Ascaris ovis* has been described from sheep in Europe and has been found in sheep in different parts of the United States. It is considered questionable by some authorities whether this parasite represents a distinct species, or whether it is only *A. lumbricoides* or *A. suum* in an unusual host.

4. LAGOCHILASCARIS MINOR Leiper, 1909

This parasite is one of the smaller ascarids which has been found occasionally in subcutaneous abscesses in man in Trinidad, B.W.I. The males are about 9 mm. and the females about 15 mm. in length. The vulva is slightly anterior to the middle of the body. The lips have a strongly developed cuticular covering and are separated from the body by a groove. The free edge of each lip is deeply indented

in the middle, giving the appearance of hare-lips. Well developed interlabia are present. Narrow flanges or alæ extend throughout the whole length of the body. The esophagus is simple. *L. minor* is probably a normal intestinal parasite of cats. *L. major* Leiper, 1910, is described from the African lion.

5. TOXOCARA CANIS (Werner, 1782)

Toxocara canis is the common ascarid of dogs and is especially frequent in puppies. These parasites are white or somewhat reddish in color and have an arrow-shaped head due to two short lateral cephalic alæ or membranous wings. The head is usually curved ventrally. The posterior portion of the male worm is curved and bears two caudal alæ. The vulva of the female is situated toward the anterior fourth of the body. The males measure from 5 cm. to 10 cm. and the females measure from 9 cm. to 18 cm. in length. The eggs are globular, 75 μ to 80 μ in diameter and have a finely corrugated or pitted shell, light brown in color (Figure 166).

The life-cycle of *T. canis* is similar to that of *A. lumbricoides*. Young dogs are particularly susceptible to infection but, when they reach the age of three or four months, the worms are automatically eliminated and the dogs then remain almost immune to reinfection. Prenatal infection with *T. canis* frequently occurs under natural conditions. The infection in puppies usually is very heavy and the puppy may show marked emaciation, enlarged abdomen, irregular appetite and often epileptiform seizures. The worms often enter the stomach and cause vomiting, with the vomitus containing many worms.

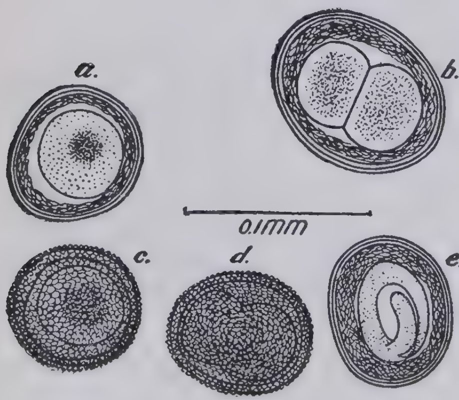


FIG. 166.—Eggs of cat and dog ascarids. *a., b., e., Toxascaris cati; c., d., Toxocara canis.* (From Hall. After Wigdor)

Toxascaris cati is a closely related species which is parasitic in cats. It is smaller than *Toxocara canis*. This species has been reported nine times from man. Its life-cycle is similar to that of *T. canis*.

II. *Family Heterakidæ* Railliet and Henry, 1914

The HETERAKIDÆ are medium to small parasites, polymyarian, with lips well defined or so reduced as to appear absent. A buccal capsule may be present or absent and when absent, the anterior portion of the esophagus is usually differentiated as a pharynx. A posterior esophageal bulb is present, except in the genus *Ascaridia* and a more or less well developed circular preanal sucker is present in the male. The vulva is typically near the middle of the body. Two genera of this family are of particular economic importance, namely *Heterakis* Dujardin, 1845, and *Ascaridia* Dujardin, 1845.

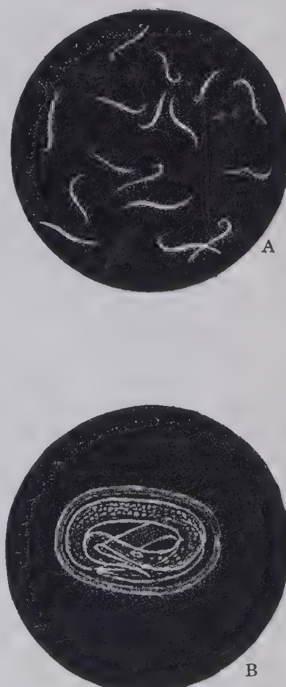


FIG. 167.—*Heterakis gallinæ*. A., adult and several immature worms, about ¾ natural size; B., infective egg showing coiled embryo within shell (about x 200). (After Tyzzer and Fabyan)

1. HETERAKIS GALLINÆ (Gmelin, 1790) Freeborn, 1923

Description. This species (Figure 167) is frequently a parasite in the cecum and rarely occurs in the small intestine, colon and rectum of barnyard and wild fowls. It is a small, rigid, white worm, with the anterior end bent dorsally from the region of the esophageal bulb. The mouth is surrounded by three small, equal lips without teeth. Each lip bears two papillæ. Two narrow lateral membranes or alæ extend almost the entire length of the body. The male is from 7 mm. to 13 mm. long and is characterized by a straight tail terminating in a subulate point with two large lateral bursal wings. There are twelve pairs of papillæ, of which four pairs are between the cloacal opening and the end of the tail, four pairs of ray-like papillæ and two pairs of sessile papillæ are in the vicinity of the cloacal opening and two pairs of ray-like papillæ are in the vicinity of the preanal sucker (Figure 168). The spicules are unequal in length, the right being 2 mm. to 2.17 mm. in length and the left 700 μ to 1.1 mm. in

length. The female measures from 10 mm. to 15 mm. in length. The tail is long, narrow and pointed and the anus is about 1 mm. from the tip. The vulva is situated slightly posterior to the middle of the body. The eggs have a thick shell, thickened at one end which thickening may enclose a lenticular clear space. They are ellipsoidal measuring from 63 μ to 75 μ in length by 36 μ to 38 μ in breadth and are unsegmented when deposited.

FIG. 168.—*Heterakis gallinæ*. Ventral view of posterior extremity of male showing circular suckers and arrangement of papillæ (x 100). (After Uribe)

Life-cycle. Under favorable conditions of temperature and moisture the infective embryo is formed within seven to twelve days. When the embryonated eggs are swallowed by susceptible birds the embryos hatch in the small intestine and pass with its contents to the large intestine from which they enter the ceca where the adult stage is reached. Larvæ may enter the ceca as early as twenty-four hours after ingestion of the eggs. These larvæ migrate into the cecal glands. At first, the larva comes to lie within the epithelial layer and later, as size increases, occupies the lumen of the gland. According to Uribe (1922), the larvæ break out of the glands in about five days and complete their development in about fifty-six days in the lumen of the cecum. Earthworms have been observed to ingest *Heterakis* eggs, and birds may become infected by eating such earthworms.

The eggs of *H. gallinæ* are very resistant. Graybill (1921) found eggs viable after sixteen to eighteen days' desiccation and eggs with live embryos after twelve months in moist soil. Many of the embryonated eggs can withstand New England winter temperatures (Uribe, 1922).

Pathogenesis. There is but little evidence that *H. gallinæ* itself produces any serious injury to the infected bird. The adult stage lives in the lumen of the ceca and is occasionally found with the head buried in the mucosa or in the cavity of lymph nodules which occur at intervals in the wall of the ceca. It generally feeds upon the cecal contents but occasionally blood may be found in its alimentary tract.

Indirectly *H. gallinæ* is a parasite of great economic importance in that it often is the vector of *Histomonas meleagridis* which causes blackhead in turkeys. Apparently, from the experimental evidence

obtained by Tyzzer (1922-1926) the germ of blackhead is carried within the egg of *Heterakis* and is protected by the shell of the latter. The actual presence of *Histomonas meleagridis* within the egg of *Heterakis,* however, has not been observed thus far.

2. ASCARIDIA LINEATA (Schneider, 1866) Railliet and Henry, 1912

Ascaridia lineata inhabits the small intestine of domestic and wild fowls and is the common roundworm of chickens in the United States. Formerly it was assumed that the large intestinal roundworm of domestic fowl in America was *A. galli,* better known as *A. perspicillum,* but Schwartz (1925) after a study of specimens from various parts of this country, pointed out that the North American species is *A. lineata* (Figure 169). Therefore, the various facts published in the United States concerning the life history and pathology of *A. galli,* or *A. perspicillum,* in all probability, refer to *A. lineata.*

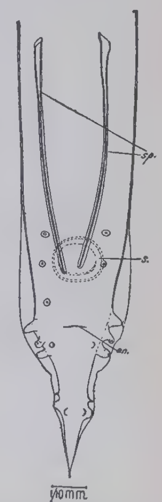


FIG. 169.—*Ascaridia lineata,* ventral view of posterior extremity of male showing circular sucker and arrangement of papillæ. *an.,* anus; *s.,* sucker; *sp.,* spicules. (After Schwartz)

A. lineata is white or yellowish in color. The male is from 55 mm. to 68 mm. in length and is characterized by ten pairs of papillæ of which three pairs constitute the first group which are arranged in a linear series on each side of the preanal sucker. A second group of four pairs, three lateral and one ventral, are in the immediate region of the cloaca and three pairs, two lateral and one ventral, are found in a secondary expansion of the caudal alæ toward the tip of the tail. The spicules are unequal with slightly enlarged, rounded points, 1.6 mm. to 2.4 mm. in length. The female may vary from 60 mm. to 95 mm. in length with the vulva at the union of the anterior and middle thirds of the body length. The eggs are elliptical, 80 μ in length by 50 μ in breadth and have thick, smooth shells.

The eggs of *A. lineata* are passed in the feces. Under favorable conditions an infective embryo is formed within nine or ten days. Such eggs, when ingested by susceptible birds, hatch in the small intestine where the larvæ develop to maturity without a migratory phase in the tissue of the host. Ackert (1923) has shown that the

larvæ may penetrate to some extent the wall of the small intestine and occasionally extend through Lieberkühn's glands into the mucosa.

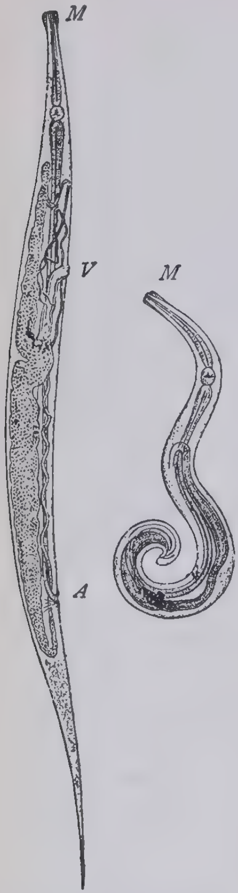


Fig. 170.—*Enterobius vermicularis*. On the left, female; on the right, male. *A*, anus; *M*, mouth; *V*, vulva. Greatly enlarged. (After Claus)

III. *Family Oxyuridæ* Cobbold, 1864

The OXYURIDÆ are parasitic, meromyarian ASCAROIDEA. The mouth is surrounded by simple, usually inconspicuous, lips and there is no buccal capsule. The esophagus is usually provided with a pharynx and always with a distinct posterior bulb, containing three valves. The caudal end of the mature female is always elongated and subulate. The male is without a preanal sucker, except in one genus, *Hoplodontophorus,* parasitic in *Hyrax,* more generally known as conies or rock rabbits of Africa and Southwestern Asia.

1. ENTEROBIUS VERMICULARIS (Linnæus, 1758)

Description. This species (Figure 170) is commonly known as the pinworm of man. It is a small, white worm with the anterior extremity surrounded by a cuticular expansion. The mouth is surrounded by three fairly distinct lips and the esophagus is provided with an extra or prebulbar swelling and a distinct bulb. Narrow lateral alæ are present which are prominent in cross sections of the worm. The male is much smaller than the female and may easily be overlooked unless special search is made for it. It measures from 2 mm. to 5 mm. in length and the posterior third of the body is curved into a spiral. The tail is blunt and possesses six papillæ and a single curved spicule, 70 μ long. The female worm measures from 9 mm. to 12 mm. in length and has a long pointed tail. The body is characteristically rigid. The vulva is very prominent and is situated in front of the posterior limit of the anterior fourth of the body. The uteri in gravid specimens are greatly distended which give a plump appearance to the body. The eggs (Figure 171, a and b) are characteristically

asymmetrical, and contain a more or less fully developed embryo when deposited by the female. The eggs vary from 50 μ to 60 μ in length by 30 μ to 32 μ in breadth.

Habitat. E. vermicularis is a parasite in the adult stage of the upper part of the large intestine. It occasionally is found in the female genital organs and bladder. It frequently occurs in the appendix and may be a cause of appendicitis. Early stages of development take place in the small intestine.

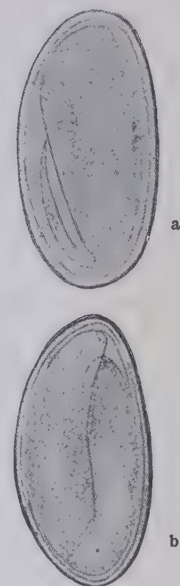


FIG. 171.—*Enterobius vermicularis.* a, egg freshly deposited, with tadpole-like embryo; b, egg twelve hours after deposition, with nematode-like embryo (x 640). (From Fantham, Stephens, and Theobald, *Animal Parasites of Man*)

Distribution. This parasite is world-wide in distribution. It is especially frequent in children, although some of the heaviest infections have been observed in adults. As many as 5,544 have been counted from a single adult after anthelmintic treatment (Hall and Augustine, 1928).

Life-cycle. The gravid females pass down the rectum and are passed out with the feces, or they may migrate from the rectum into the anal cleft, the genitocrural folds and the neighboring parts. When the females become exposed to air, a definite physiological reaction follows in the form of rhythmical contractions of the wall of the vagina which expells the eggs, and, as the worm advances, the eggs are left behind in its trail. The tadpole-like embryo quickly develops into a coiled, nematode-like form which, when swallowed by man, develops directly into the adult stage. The females creep out of the rectum usually at night and in so doing cause intense itching. Scratching, to alleviate the itching, results in the eggs adhering to the hands, especially under the finger-nails. These eggs may sooner or later be conveyed to the mouth directly from the hands, or to food or drink. Eggs may also adhere to the night-clothes and bed linens and thus may be conveyed to persons handling them.

Upon ingestion of the infective eggs, the embryos hatch in the small intestine where the young worms develop to sexual maturity. After the females are fertilized the uteri begin to fill with eggs and the females soon pass down the rectum to discharge them. The duration of the cycle is about two weeks.

Certain writers have reported the simultaneous finding of eggs, larvæ and adults in the intestine, or the existence of *Enterobius*

larvæ in fresh feces, or a six to seven week periodicity in the passage of female worms. These observations suggested that the eggs may hatch after deposition in the intestine without passing out of the patient, or in other words, a multiplication of individuals may occur within the intestine of the host. This, however, lacks experimental proof and needs further investigation.

Pathogenesis. In migrating out from the rectum the female worms produce an intense itching, and when occurring in large number, a severe anal pruritus may result. The worms may also travel to the vulva and the resultant irritation sometimes leads to masturbation. The itching is more intense at night and may result in loss of sleep and of nervous energy. The patient is often anemic and emaciated from disturbances of appetite and of nutrition and in some cases there are nervous disturbances. *Enterobius* is frequently found in the appendix and is believed by many observers to have a definite pathogenic rôle in the causation of appendicitis. Harris and Browne (1925) reported *E. vermicularis* in twenty-two appendixes out of an uninterrupted sequence of 121 cases of operative appendicitis and concluded that the failure of recognition of *Enterobius* as a factor in the production of appendicitis is due in general to the lack of detailed gross and microscopic study of the appendix.

Diagnosis. Infections with *Enterobius* are diagnosed on the presence of characteristic symptoms and on the finding of the gravid females. A simple examination of the anus will frequently establish the diagnosis. Eggs are rarely found in the host's feces because of the egg-laying habits of the female worm. In infected individuals, however, eggs may frequently be found in scrapings from the fingernails.

Treatment. Santonin, chenopodium, thymol, carbon tetrachloride and tetrachlorethylene have been used with success against *Enterobius,* especially against those forms living in the small intestine. A number of substances have been used as enemas for removing the gravid females from the large intestine. Among enemas which have been recommended (Hall, 1923) are cold water; sodium chloride or vinegar diluted 3 or 4 times with water; 1 per cent acetic acid, 15 to 25 drops of oil of chenopodium shaken up in a liter of water; phenol and glycerin, 5 to 10 minims of each in one pint of water; quassia, one ounce steeped in one pint of hot water, and solutions of lime water or formaldehyde. The use of an anal wash or ointment is generally advised to destroy the worms and eggs, to alleviate itching and make less likely the transfer of infective material to the hands, bed clothing and to the mouth.

Prevention. Rigid personal cleanliness is essential. Underwear, night-clothes, and bedding of infected persons should be handled with caution and properly laundered to insure the destruction of infective ova. Infected individuals should guard against auto-infection. The anal region should be thoroughly cleansed after defection followed by the application of an anal ointment. The use of night-clothes which will prevent contamination of the fingers by scratching during sleep is advised for infected children. Separate beds for infected persons will help prevent the spread of the infection. In addition to the usual measures against *Enterobius* a diabetic diet is sometimes advisable.

2. OXYURIS INCOGNITA Kofoid and White, 1919

This species was named by Kofoid and White (1919) on the finding of certain peculiar nematode eggs in the stools of 427 soldiers at Camp Travis, Texas, and of various military units of the Southern Department. This egg has also been noted by others in different parts of the world. It characteristically occurred sporadically in the stool. No adult worms were obtained from any of the patients. Measurements of the eggs gave an average length of 95 μ and an average width of 40 μ. It was marked by the asymmetry typical of oxyurid eggs and the name *Oxyuris incognita* was tentatively given it. Recently Sandground (1923) has shown that the eggs described by Kofoid and White are eggs of *Heterodera radicicola,* a very common root parasitic nematode of radishes, celery, carrots, turnips and other vegetables. The eggs of *H. radicicola* when ingested by man with green vegetables can pass, apparently uninjured, through the alimentary tract, and their presence in the feces might easily be regarded as an indication of a nematode infection.

3. OXYURIS EQUI (Schrank, 1788)

This species inhabits the large intestine of the horse, ass and mule. The males are about 1 cm. in length and the females vary from 4 cm. to 15 cm. in length. The body is usually white, somewhat thickened and curved. The posterior portion of the female may be much attenuated. *O. equi* produces an anal pruritus in horses such as *Enterobius vermicularis* does in man. To alleviate the itching, the infected animals rub the parts against objects and thus wear off the hair and skin from the base of the tail.

Treatment. Hall (1923) recommends 4 or 5 drachms of oil of chenopodium followed immediately by a quart of raw linseed oil. Rectal enemas are sometimes used but, according to Hall, they give results inferior to those obtained by the use of oral medication.

4. SYPHACIA OBVELATA (Rudolphi, 1802)

Syphacia obvelata (Figure 172) is a common oxyurid in the cecum and large intestine of mice and rats. The female worm measures from 3.5 mm. to 5.7 mm. in length. The eggs are 110 μ to 142 μ in length by 30 μ to 40 μ in breadth. The embryo is not formed at the time of oviposition. This parasite has been reported from an American-Bohemian child living in Zamboanga.

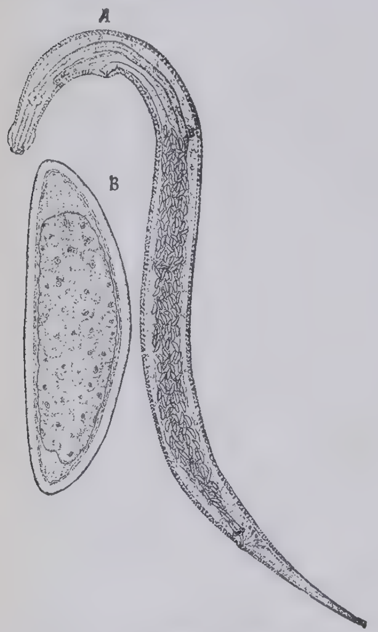


FIG. 172.—*Syphacia obvelata.* A, Female from the cecum of a mouse; B, egg. Enlarged. (After Riley)

Aspiculuris tetraptera (Mitzsch, 1821) is also a common oxyurid of rats and mice in the United States. This species is somewhat smaller than *S. obvelata.* The eggs are much smaller than those of *S. obvelata* ranging from 84 μ to 90 μ in length by 34 μ to 40 μ in breadth. *Passalurus ambiguus* Rudolphi, 1819, is a common parasite in the cecum and large intestine of rabbits. These oxyurids are usually obtainable for laboratory study.

IV. *Family Rhabditidæ* Micoletzky, 1922

The RHABDITIDÆ is composed of small nematodes, free-living or parasitic, or with both free-living and parasitic phases. The buccal cavity may be three-sided, prismatic or tubular, and usually without teeth. The esophagus generally has a posterior bulb containing valves, and frequently there is a prebulbar swelling. The cuticula is without bristles, or if present, they are very few in number. The female is either oviparous or viviparous, and not infrequently parthenogenetic or hermaphroditic.

I. RHABDITIS HOMINIS Kobayashi, 1914

Most species of the genus *Rhabditis* are free-living. They are especially common in decaying matter. The parasitic species occur mostly in insects but a few forms have been reported in man.

Rhabditis hominis (Figure 173) was first noted in 1914 by Kobayashi (1921) from feces of pupils of a primary school of Japan and has since been observed in human feces in the United States. The female is viviparous and all stages of its development were found in the same specimen of feces. When present in the feces they occur in very great numbers. Their length of life is apparently short, for pupils who were found to harbor the worms by fecal examination in October and November, 1913, were all found parasite free on their reëxamination in January, 1914, which fact, as Kobayashi states, shows that the worm may not be a true parasite, but one that happened to find a temporary or accidental lodgment in the human body. Sandground (1925) was unable to obtain an infection with *R. hominis* in either the human subject or in laboratory animals and regards it as a free-living coprophagous species which may appear in the feces as a result of soil contamination or by its introduction into the feces by filth flies. The full-grown female measures about 2 mm. in length and the length of the male is about 1 mm.

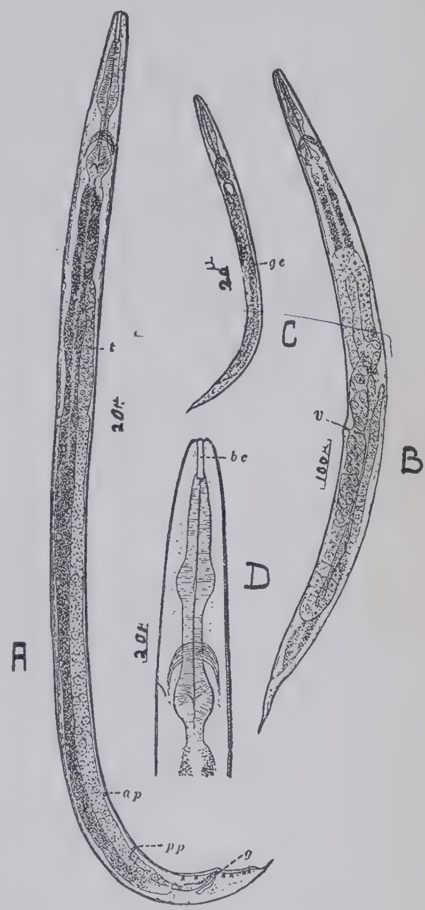


FIG. 173.—*Rhabditis hominis.* A, adult male; B, young female; C, young rhabditiform larva; D, anterior portion of an adult worm showing characteristics of the esophagus. (After Sandground)

Among other species of *Rhabditis* reported as parasites of man are *R. pellio* Schneider, 1866, and *R. niellyi* R. Blanchard, 1885. *R. pellio* has been reported from the urine and vagina of a woman from Hungary. It normally lives during the adult stage in decomposing matter in the soil and in its larval stage may be parasitic in the nephridia of earth worms. *R. niellyi* was obtained from itching papules on the skin of a boy living in Brest.

2. GENUS RHABDIAS Stiles and Hassall, 1905

The members of the genus *Rhabdias* are usually found inhabiting the lungs of amphibians and reptiles. They are heterogenetic nematodes. The parasitic generation consists of "female" forms only, which are hermaphroditic or parthenogenetic in function. The free-living generation are microscopic forms, sexes separate with fairly stout bodies. The infective larvæ are sheathed forms. *Rhabdias bufonis* from the frog and toad and *Rhabdias fuscovenosa* from the grass snake are typical examples of this genus.

3. STRONGYLOIDES STERCORALIS (Bavay, 1876)

Historical. Strongyloides stercoralis was first discovered by Dr. Normand in 1876 in the feces of French Marines from Cochin China who were suffering from severe diarrhea. Bavay described the parasites as *Anguillula stercoralis.* Dr. Normand later found nematodes which were morphologically different from those first observed in the feces at autopsy in the intestine of patients who had died of diarrhea. These were diagnosed by Bavay as *Anguillula intestinalis*. Both forms were believed to be the cause of the disease, then known as Cochin China diarrhea. Leuckart in 1882 studied the life-cycle of this parasite and demonstrated that the two forms found by Dr. Normand were two succeeding generations of the same species, that *A. intestinalis* lived parasitically in the intestine, and *A. stercoralis* is its progeny which attains maturity in the open and there multiplies.

Distribution. Strongyloides stercoralis is world-wide in distribution and is especially frequent in tropical and sub-tropical countries where the lack of sanitation and climatic conditions are most favorable for the development of the free-living generation. It is a natural parasite of man but can develop in dogs and cats. In dogs the infection disappears suddenly after two to three weeks and this animal is therefore to be considered an abnormal host for this parasite. The duration of the infection in cats is not known.

Description. (1) *The parasitic generation:* the parasitic generation of *S. stercoralis* (Figure 174) consists only of the female worm which is, at present, generally held to be parthenogenetic, but according to the work of Sandground (1926) it is hermaphroditic. Further investigation is needed, however, on this point. It is colorless, more or less transparent and approximately 25 mm. in length. The body tapers anteriorly and ends in a conical tail. The vulva is situated near the posterior third of the body. This parasite may be recognized by the prominent uteri which contain about ten eggs arranged in single file. The eggs measure from 50 μ to 58 μ in length by 30 μ to 34 μ in breadth and are in the later stages of segmentation when they are extruded from the vagina. Further development and hatching take place in the intestinal mucosa and the newly hatched larvæ make their way into the lumen of the intestine. The larvæ are then passed to the exterior with the feces (Figure 175). Because of the early hatching of the eggs within the intestine, it is only in cases of severe diarrhea or after purgation that the ova may be present in the evacuated feces. The newly hatched larvæ possess

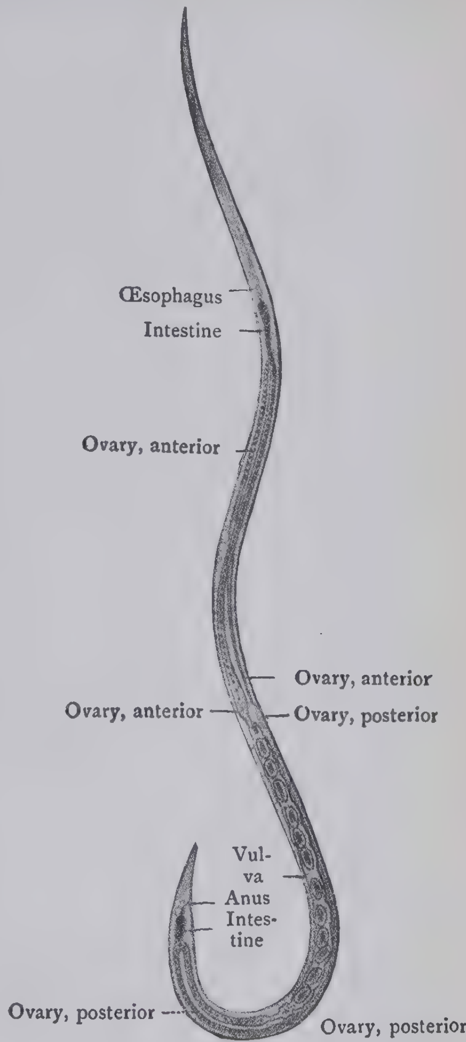


FIG. 174.—*Strongyloides stercoralis*, female of the parasitic generation from intestine of man (x 70). (From Fantham, Stephens, and Theobald, *Animal Parasites of Man*. After Looss)

a double-bulbed esophagus, characteristic of many free-living nematodes, and are known as rhabditiform larvæ. They possess a complete digestive system but sexual organs remain undeveloped. The rhabditiform larvæ feed in the open and later may metamorphose either into elongated, filariform larvæ or, under certain conditions, into free-living adult male and female worms.

FIG. 175.—*Strongyloides stercoralis*, larva from fresh human feces (x 170). (From Fantham, Stephens, and Theobald, *Animal Parasites of Man*. After Looss)

(2) *The free-living generation:* The free-living generation of *S. stercoralis* consists of both sexes which are typical, free-living nematodes possessing a double-bulbed, muscular, or rhabditiform esophagus. The female worm is smaller than the parasitic stage, measuring only about 1 mm. in length. The male is somewhat smaller. After copulation the female produces eggs from which rhabditiform larvæ emerge which are indistinguishable from the rhabditiform larvæ produced by the parasitic female. These larvæ, after a short feeding period, metamorphose into filariform, or infective larvæ (a non-feeding stage) (Figure 176).

Life-cycle. The rhabditiform larvæ which are expelled from the host feed upon the host's feces and within a short time may metamorphose directly into elongated, infective larvæ, or develop into free-living adult males and females which later copulate and whose end product is an infective filariform larva. Whether the development of the infective larvæ is direct or indirect, they are morphologically identical and possess the same biological characteristics. They are about 550 mm. in length and may be readily distinguished by their long slender esophagus which has a length almost half the total length of the body and a distinct cleft at the tip of the tail, seen only with the high power of the microscope. Under natural conditions, these larvæ occupy the very upper parts of the soil, and when occurring in great numbers, they form themselves into white, polyp-like masses on the exposed soil aggregates. Infection results when the filariform larvæ penetrate the host's tissues, the opportunity for infection usually being offered when a barefooted individual passes through areas of infected soil. The position of the infective larvæ in the soil makes ideal their transfer to the foot. Infection may also

be acquired by drinking water containing the infective filariform larvæ, but it is doubtful if this occurs frequently under natural conditions.

After the larvæ penetrate the epidermis of the host, they are carried by the blood stream to the lungs where some development takes place, after which development they crawl up the trachea and down the esophagus, and through the stomach to the small intestine where they grow into the parasitic, parthenogenetic or hermaphroditic female in about five to seven days. The diagram on page 380, after Sandground, graphically illustrates this life-cycle.

Sandground (1926) finds that while the life-cycle in certain species, such as *S. fülleborni* always involves an indirect development with the interpolation of the free-living sexual generation, in other species, such as *S. stercoralis,* both the direct and indirect types of development occur.

A number of writers have reported the finding of filariform larvæ in fresh feces and sputum (Gage, 1910-1911; Shimura and Ogawa, 1920) which indicates that under certain conditions the rhabditiform larvæ can pass into the infective stage while still within the host, thereby making auto-infection possible. There is, however, no experimental evidence

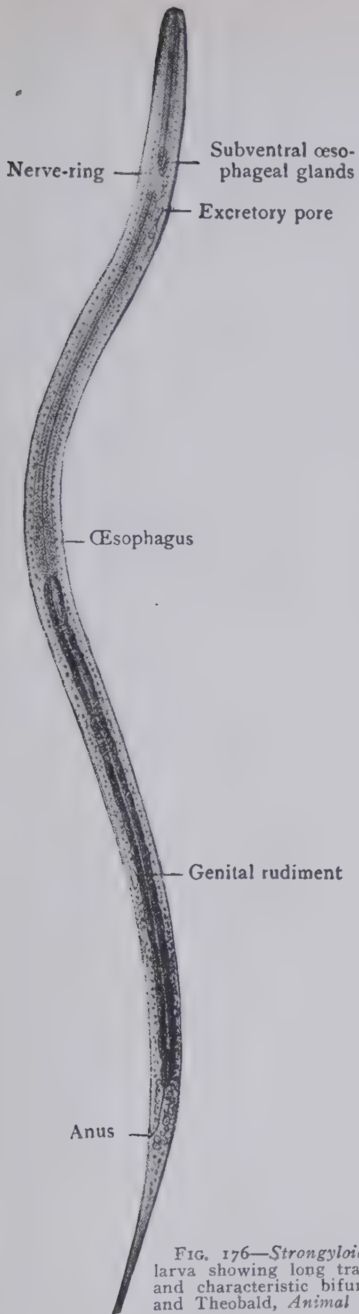


Fig. 176—*Strongyloides stercoralis,* the infective stage of filariform larva showing long transparent esophagus, slender granular intestine and characteristic bifurcation of the tail. (From Fantham, Stephens, and Theobald, *Animal Parasites of Man.* After Looss)

Free-living, bisexual generation
↓
Eggs
↓
Rhabditiform larvæ
↓
Filariform larvæ
↓
Parasitic, monosexual generation (♀)
↓
Eggs
↓
Rhabditiform larvæ
↓
Filariform larvæ

Indirect development (*heterogony*)

Direct development (*homogony*)

thus far proving that auto-infection with *S. stercoralis* does occur.

Pathogenesis. S. stercoralis was early attributed to be a cause of diarrhea and dysentery, but these diseases have since been found to be due to other agents. The presence of the worm deep in the intestinal mucosa must, however, produce considerable irritation, especially when occurring in great numbers, and may intensify a diseased condition brought about by other causes. The infective larvæ may produce a more or less severe cutaneous irritation at the site of their entrance to the host.

Treatment. Strongyloides is difficult to expel from the host as it lies buried in the mucosa and is thus protected against the vermicidal action of anthelmintics now used in the treatment of roundworm infections.

Prevention. Measures used against hookworm infection are equally effective against *Strongyloides*. See page 407.

4. STRONGYLOIDES OF LOWER VERTEBRATES

Strongyloides canis Brumpt, 1922, was first described from dogs of the Orient by Fülleborn in 1914. This species also occurs in Oriental cats. Morphologically it is indistinguishable from *S. stercoralis*, and it, together with *S. nasua* Darling, 1911, from the coati, *Nasua* sp., are, according to Chandler (1925) varieties of *S. stercoralis*. *S. papillosus* (Wedl, 1856) Ranson, 1911, in sheep, goats, rabbits and antelope, *S. suis* von Linstow, 1905, in the pig, *S. siminæ* Hung See-Lu and Höppli, 1923, *S. fülleborni* von Linstow, 1905, from old world primates and *S. cebus* Darling, 1911, in *Cebus*, sp., are considered by Sandground (1925) and Goodey (1927) as distinct species, while Chandler (1925) regards them as subspecies of *S. papillosus*. *S. ratti* Sandground, 1925, is said to occur in about 60 per cent of rats caught on refuse dumps in Baltimore and may be a very common parasite of rats in the United States.

CHAPTER XXVII

THE ORDER STRONGYLOIDEA

The STRONGYLOIDEA consists entirely of parasitic nematodes, the males of which possess a conspicuous terminal or subterminal bursa copulatrix, supported generally by six paired rays and one unpaired dorsal ray with accessory branches. All the rays extend outwards from a common center. The esophagus is usually more or less club-shaped posteriorly, but without a definite spherical bulb and without a valvular apparatus.

This order is divided into seven families, according to Baylis and Daubney, (1926), of which the STRONGYLIDÆ Baird, 1856, ANCYLOSTOMIDÆ Looss, 1905, METASTRONGYLIDÆ Leiper, 1908, and TRICHOSTRONGYLIDÆ Leiper, 1912, are of particular interest in medical zoölogy.

I. *Family Strongylidæ* Baird, 1853

This family is characterized by a well developed buccal capsule the anterior margin of which is without teeth or cutting plates, but usually bears a corona radiata or leaf crown consisting of narrow, flattened leaf-like processes with pointed or rounded tips according to the species (Figure 177). Five subfamilies of STRONGYLIDÆ are recognized by Baylis and Daubney (1926) of which four are of special interest here.

1. SUBFAMILY STRONGYLINÆ Railliet, 1893

STRONGYLIDÆ with a relatively large buccal capsule which is more or less subspherical or infundibular. A dorsal gutter forms a ridge in the wall of the buccal capsule and extends nearly to its anterior margin. They are parasites of the alimentary tract of vertebrates. Examples: *Strongylus vulgaris, Triodontophorus servatus* in equines.

2. SUBFAMILY TRICHONEMINÆ Railliet, 1916

STRONGYLIDÆ with a cylindrical buccal capsule with relatively thick walls. The dorsal gutter is comparatively short and does not

reach the anterior margin of the buccal capsule. There is no ventral cervical or cephalic vesicle. The TRICHONEMINÆ are parasites of the alimentary tract of vertebrates. Examples: *Trichonema tetracanthum, Gyalocephalus capitatus* in equines.

(1) STRONGYLUS VULGARIS (Looss, 1900). *Strongylus vulgaris,* together with species of other closely related genera, *Triodontophorus* Looss, 1902, *Gyalocephalus* Looss, 1900 and *Trichonema* Cobbold, 1874, are perhaps the most important nematodes parasitic in horses and other EQUIDÆ. These strongyles are practically world-wide in distribution but occur most frequently in the warmer countries where conditions are most favorable for the development of the free-living stages. They often occur in mixed infections and in very great numbers.

The adults of the genera *Strongylus* and *Triodontophorus* are essentially blood suckers and are usually found firmly attached to the wall of the cecum or colon by the buccal armature producing lesions at the point of attachment. When occurring in great numbers they are associated with anemia which in turn is naturally associated with emaciation, edema and ascites. The adults of the genus *Trichonema,* however, are not blood suckers and do not adhere to the mucous membrane. They feed mainly upon the contents of the intestine of the host. According to Kotlán (1919) they may cause a hemorrhagic inflammation of the mucosa when occurring in great numbers.

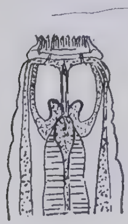


FIG. 177.—Anterior extremity of *Strongylus vulgaris,* showing "leaf crown." (After Riley)

They, like other strongyles, have a direct life-cycle. The eggs are passed in the manure and subsequently give rise to an infective larval stage on the pasture land. When these infective larvæ are ingested by the horse or other EQUIDÆ, they take different routes in the body and undergo somewhat different lines of development, according to the species involved.

The infective larvæ of *Strongylus vulgaris* make their way in the posterior mesenteric artery where they set up an endarteritis resulting in the formation of an aneurysm. After a certain time in the aneurism, the larvæ reach the cecum and become encysted in the submucosa where further development takes place. They finally pass to the lumen where they attach themselves to the mucosa and acquire the characters of the adult.

The aneurysm produced by the larval parasites are particularly dangerous as they may rupture causing the death of the host from

hemorrhage, or fragments of the clot may break off forming emboli, which may obstruct the blood supply to a portion of the intestine and thereby cause a cessation of peristalsis. The contents of the affected portion undergo fermentation and the intestine then becomes distended with gas. Symptoms of colic may be evident. Occasionally the gas formation may cause a rupture of the intestine, stomach or diaphragm. As these aneurysms persist even after the worms have passed into the intestine, there remains a constant threat to the life and health of the host.

Treatment. According to Ransom and Hall (1920) the strongyles of the large intestine may be readily removed by fasting the animal for thirty-six hours and administering 4 to 5 drams of oil of chenopodium, immediately preceded or followed by a quart of linseed oil.

3. SUBFAMILY ŒSOPHAGOSTOMINÆ Railliet, 1915

STRONGYLIDÆ with a cylindrical or large and subglobular buccal capsule and with a transverse, ventral cervical groove and a more or less pronounced cephalic vesicle. Parasites of the alimentary tract of mammals. Examples: *Œsophagostomum columbianum* in sheep and goats, *Œ. brumpti* in man, *Ternidens deminutus* in man and monkeys.

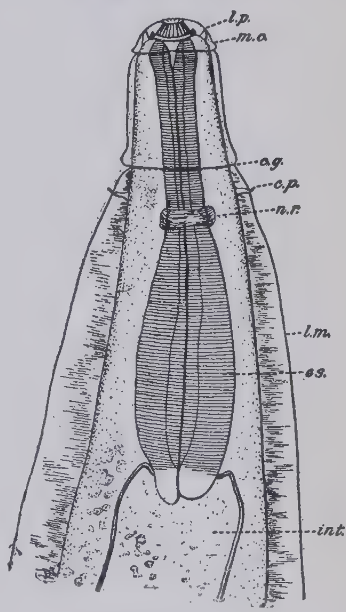


FIG. 178.—*Œsophagostomum columbianum.* Anterior end of the body. Ventral view. *c.g.*, cervical groove; *c.p.*, cervical papilla; *es.*, esophagus; *int.*, intestine; *l.m.*, lateral membrane; *l.p.*, lateral circumoral papilla; *m.c.*, mouth collar; *n.r.*, nerve ring (x 75). (After Ransom)

Œsophagostomum columbianum Curtice, 1890 (Figures 178 and 179), is commonly known as the "nodular worm" of sheep and goats. The female worms attain a length of about 15 mm. and the males about 14 mm. Both sexes have a characteristic solid white color and the head is bent over so as to form more or less of a hook with the body. The eggs measure from 65 μ to 75 μ in length and from 40 μ to 45 μ in width.

This species is very common in sheep in the United States, being

especially prevalent in the Southern and Eastern States and less frequent in the Middle West. Its life history is incompletely known. When the young worms are first found in the sheep they are encysted in the wall of the intestine. The nodules are most frequent in the wall of the cecum and large intestine but may also occur in the liver and other abdominal viscera. They are at first very small, but gradually increase in size, becoming filled with a mass of greenish caseous material upon which the developing larva feeds. After the larva has undergone a certain amount of growth and development, it crawls out of the nodule and enters the lumen of the large intestine where it completes its development to maturity.

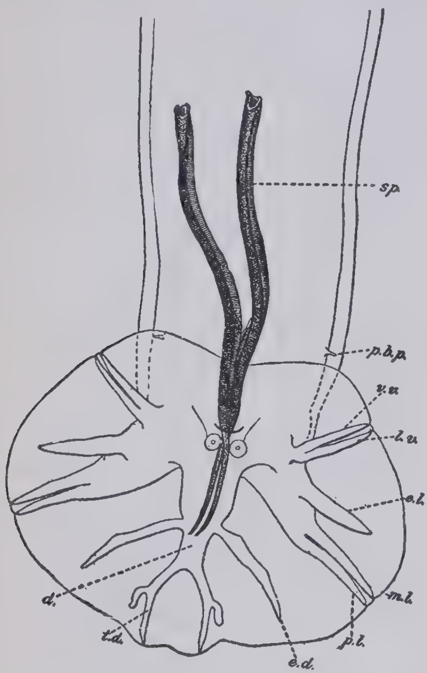


FIG. 179.—*Œsophagostomum columbianum.* Posterior end of body of male with bursa spread out. Ventral view. *d.*, dorsal ray; *e.d.*, externo-dorsal ray; *e.l.*, externo-lateral ray; *l.v.*, lateral-ventral ray; *m.l.*, medio-lateral ray; *p.b.p.*, prebursal papilla; *p.l.*, posterior-lateral ray; *sp.*, spicule; *t.d.*, terminal branch of dorsal ray; *v.v.*, ventro-ventral ray (x 75). (After Ransom)

Nodular disease is more or less injurious according to the severity of the infection and the age and vitality of the individual. In severe cases diarrhea and emaciation may be excessive. Affected intestines, so-called "knotty guts," are unfit for sausage casings.

Treatment and prevention. No effective medicinal treatment is known for this parasite. Pasture rotation, however, is a valuable control measure.

Œsophagostomum radiatum occurs in cattle. The location of the nodules is more often in the small intestine than in the large intestine. *Œ. dentatum* is a parasite of pigs. The nodules appear most frequently in the large intestine.

Several species of *Œsophagostomum* which are natural parasites of monkeys and gorillas, have been reported in man. They are therefore accidental parasites of man. Their presence in the cecum and large intestine causes tumors similar to those described under

Œ. columbianum. Œ. brumpti Railliet and Henry, 1905, was discovered by Brumpt during an autopsy of a native of the River Omo (Lake Rudolph), East Africa, and again later after anthelmintic treatment to a negress of New Guinea by Joyeux. *Œ. brumpti* also occurs in apes. *Œ. stephanostomum* var. *thomasi* appears to be a fairly common parasite of man in certain parts of Brazil, and also occurs in the large intestine of the gorilla. *Œ. apiostomum* is a natural parasite of monkeys and has been reported in man in Northern Nigeria.

Ternidens deminutus (Railliet and Henry, 1905) was first found in the large intestine of a negro of the Comoro Islands and later in natives of Nyassaland. It also occurs in Asiatic monkeys which perhaps are the natural hosts.

4. SUBFAMILY STEPHANURINÆ Railliet, Henry and Bauche, 1919

STRONGYLIDÆ with a well developed, cup-shaped buccal capsule and with a leaf crown at its anterior margin. The bursa of the male is subterminal and poorly developed, with stunted rays. They are parasites in the perirenal fat or kidneys, abdominal viscera and more rarely in the liver and lungs of mammals. Examples: *Stephanurus dentatus* Diesing, 1839, in the perirenal fat of pigs.

(1) STEPHANURUS DENTATUS Diesing, 1839. This species is generally known as the "kidney worm" of pigs and usually occurs in the fatty tissue surrounding the kidneys. It is reddish in color and has a mottled appearance due to the folds of the intestine and reproductive organs which show through the more or less transparent cuticula. Its presence may cause cyst-like formations in the adipose tissue which on incision usually show one or two worms and a certain amount of pus. Apparently no particular damage is done the host by these parasites.

5. SUBFAMILY SYNGAMINÆ Baylis and Daubney, 1926

STRONGYLIDÆ with buccal capsule well developed, subglobular, without leaf crowns at its anterior margin but with teeth at its base. The eggs are operculate. The SYNGAMINÆ are parasites of the respiratory tract of birds and mammals. Examples: *Syngamus trachea* in fowl, *S. kingi* in man.

(1) SYNGAMUS TRACHEA (Montagu, 1811). *Syngamus trachea* is a slender, red worm which is frequently found in the trachea and air passages of domestic fowl and wild birds. It is commonly known

as the "gape worm" of chickens. The male measures from 2 mm. to 6 mm. and is permanently attached in copula to the female. The female measures from 5 mm. to 20 mm. in length. The eggs measure about 85 μ in length by 50 μ in breadth and contain a developed embryo at the time they leave the host. They are further characterized by the presence of a roundish opening closed by a delicate membrane at each pole, through which the embryo makes its escape. The eggs may be swallowed by the infected bird and thus appear in the feces or they may also be present in the discharges which are coughed up by the bird. The eggs hatch in the open within seven to forty days, according to the temperature of the environment. The birds become parasitized by ingesting the infective larvæ with food or drinking water. These larvæ penetrate the wall of the gullet and finally become established in the lungs where they grow to maturity. They occur most frequently near the division of the trachea into the bronchi.

The presence of the worms may produce a severe catarrh, and occasionally small abscesses are found at the site of attachment of the worm by their buccal capsule to the host. Usually from three to thirty worms are present.

The infected birds cough and shake their heads repeatedly in their efforts to expel masses of mucus and the worms. They frequently open their bills, hence the derivation of the name "gapes," and they have a whistling breath. Young chickens suffer most. Emaciation develops in spite of good appetite and death may be due to asphyxiation. Turkeys are susceptible to infection at any time of life but are little affected by the parasite. They serve as carriers of infection and are looked upon as the normal host of the gapeworm.

Treatment. The worms located in the upper portion of the trachea can often be extracted by the aid of long forceps. Intratracheal injections of about fifteen drops of a 5 per cent solution of salicylate of sodium are said to produce good results.

Prevention. Bodies of all dead birds and feces from poles and roosts should be burned, and sick birds separated from healthy ones. Feeding and drinking places should be kept clean. As *S. trachea* also occurs in a large number of wild birds, including pigeons, blue jays, swallows, starlings, crows, pheasants and partridges, those species frequenting chicken yards, especially crows and swallows, should be fenced out or destroyed. Chickens should be kept separated from turkeys.

Syngamus kingi Leiper, 1913, was discovered by Dr. King of St. Lucia in the sputum of a negress suffering from a chronic cough

and was described by Leiper. Morphologically this parasite is similar to *S. dispar* in the lungs of the cougar, *Felis concolor*. The infection in man is purely accidental.

II. *Family Ancylostomidæ* (Looss, 1905) Lane, 1917

STRONGYLOIDEA with well developed buccal capsule bearing ventral teeth or cutting plates on its anterior margin. These nematodes are parasites of the alimentary tract in mammals. According to Baylis and Daubney (1926) this family contains two subfamilies, (1) ANCYLOSTOMINÆ (Looss, 1905) Stephens, 1916; and (2) NECATORINÆ Lane, 1917.

1. SUBFAMILY ANCYLOSTOMINÆ (Looss, 1905) Stephens, 1916

ANCYLOSTOMIDÆ with the anterior margin of buccal capsule armed ventrally with from one to four pairs of teeth and with the mouth directed obliquely dorsally. Example: *Ancylostoma duodenale* in man.

(1) ANCYLOSTOMA DUODENALE DUBINI, 1843. *Historical. Ancylostoma duodenale,* or the so-called Old World hookworm of man, was not discovered until 1838, but there is much evidence that the disease caused by it has been of very long standing. Hippocrates, about B.C. 440, described a disease that might well be due to hookworms; those suffering from it ate stones and earth, had great intestinal disturbances and were jaundiced. The striking pallor of miners is also noted in the works of Lucretius and Lucan (B.C. 50 and A.D. 50), and it was believed that gold gave off evil exhalations which turned those digging for it the same color as the metal itself. Khalil (1922) believes the earliest valid record of *Ancylostoma* and ancylostomiasis was made in the Arabian "Laws of Medicine" dated 525 Hegira or A.D. 1131, by Avicenna. Roundworms were found high in the small intestine by Avicenna and it was noted that these worms were frequent in boyhood and adult life and less in old age. From 1611 to 1800 epidemics of a disease in Brazil were described under various names, such as anemia, dropsy, intestinal disturbances and weakness, all of which are symptoms which coincide with those of hookworm disease, and it was noted that it was particularly a cause of death among negro slaves.

Before the hookworm was finally discovered in man, a number of related species had been described from animals. Goeze in 1782 discovered roundworms in the intestine of a badger which he described as *Ascaris criniformis*. He noted a membranous expansion at the

posterior end of the male with two rib-like structures which he called hooks. Froelich in 1789 found similar worms in the intestine of foxes, and because of the membranous expansion of the tail of the male and the so-called hooks, he called them "Haakenwürmer" or "hook-worms," and gave the name *Uncinaria* to the genus.

Hookworms in man were first discovered in 1838 by Angelo Dubini, an Italian physician, during an autopsy on a peasant woman who had died of pneumonia in a Milan hospital. But little attention was given to this discovery until four years later when Dubini discovered a second infection with these worms, which he named *Agchylostoma duodenale.* He found this parasite in 20 per cent of the cases examined and in some of these the numbers of worms was so great that he ascribed death to their presence in the absence of other lesions. Soon after Dubini's discovery, *Ancylostoma* was found in Egypt and it was associated with the extremely prevalent chlorosis in that country. Hookworms were found in 1866 by Wucherer in Brazil in the bodies of patients who had died of tropical anemia and subsequent observations by Brazilian physicans established that these parasites were the cause of a severe and widely prevalent disease.

In 1878 Grassi and Parona discovered that hookworm disease could be recognized from eggs passed in the feces, and from then on it became the custom to search for hookworm eggs in the feces of suspected cases.

As the disease was largely confined to tropical and subtropical regions it attracted but little attention among medical men in countries north of the Alps until 1880, when an epidemic of anemia developed among the laborers at the Saint Gotthard tunnel in Switzerland. Perroncito, an Italian scientist, recognized the parasitic nature of the so-called "tunnel-disease" and proved to those of opposite opinions that the anemia could be cured by vermifuges that expelled the worms. After the completion of this tunnel the laborers sought work in Central European mines and brick fields and carried the infection with them. The disease became most severe in the gold and silver mines of Hungary, in the coal mines of Germany, Holland, Belgium and France, in the lead mines of Spain, in the tin mines of England and in the sulphur mines of Sicily.

The exact method by which man becomes infected with *Ancylostoma* remained unknown until the close of the century. It was early believed that the larvæ could withstand great periods of desiccation and might be transported by air currents or in dust. It was also held that animals, especially the horse, were reservoir hosts and in some

mines of Hungary horse-haulage was discontinued. Through experimentation, however, it became evident that none of the lower animals is a carrier of *Ancylostoma duodenale* or *Necator americanus*, the important hookworms of man.

Leichtenstern and others showed experimentally that infection may result from infective larvæ entering the body by way of the mouth either with contaminated food or water. The usual mode of entrance was discovered, however, quite by accident. Looss, in 1898, during his studies on *Ancylostoma* in Egypt, spilled a hookworm culture on his hand and noticed that a dermatitis soon developed at that spot. Later he found hookworm ova in his feces and concluded that he had been infected through the skin. He then proved experimentally this theory of dermal infection and traced the migration of the larva from the time it enters the body until it finally becomes established in the small intestine, the habitat of the adult worm (Looss, 1911).

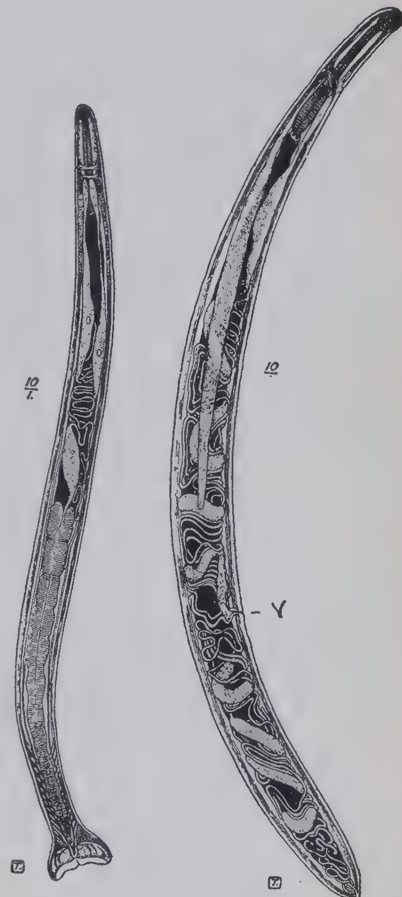


Fig. 180.—*Ancylostoma duodenale.* Male and female. V, vulva. (From Manson-Bahr's *Manson's Tropical Diseases.* After Looss)

In 1902, Dr. Stiles described a new species of hookworm, *Necator americanus,* in man from the United States and Porto Rico. Hookworms in the Americas had been observed much earlier (1888) in Brazil but they were not recognized as a distinct species. It was soon discovered that much of the anemia in certain southern states and Porto Rico was due, not to malaria, but to this new species of hookworm (Ashford and Gutierrez, 1911) and sooner or later various state boards of health took active measures against it. The pioneer work of Stiles and others led to the

creation of the Rockefeller Sanitary Commission in 1909 for the purpose of combating hookworm disease, and in 1915 the work of that organization was merged with that of the International Health Board of the Rockefeller Foundation which now coöperates with governments throughout the world in the fight against hookworm disease as well as carrying on other public health activities.

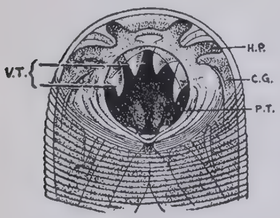


Fig. 181.—*Ancylostoma duodenale.* Showing hook-like central teeth. C.G., cephalic gland; H.P., head papillæ; P.T., pharyngeal teeth; V.T., ventral teeth (x 50). (From Manson-Bahr's *Manson's Tropical Diseases.* After Looss)

Distribution and frequency. Ancylostoma duodenale occurs in practically all countries which lie in the tropical and subtropical zones, extending from parallel 36 degrees north to parallel 30 degrees south. It is dominant in Europe whence it is believed to have been carried to Africa, Asia and the Americas. It usually is found in mixed infections with *Necator americanus,* commonly known as the New World hookworm, but occurs alone in Egypt. In the United States *Ancylostoma duodenale* occurs only in miners and not among the surface population.

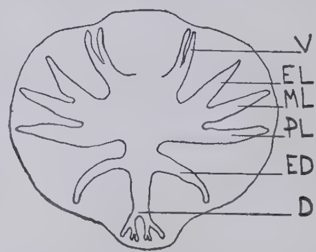


Fig. 182.—Diagram of the posterior end of male with bursa spread out. Ventral view. V, ventral rays; EL, externo-lateral rays; ML, medio-lateral rays; PL, posterior-lateral rays; ED, externo-dorsal rays; D, dorsal rays. (Redrawn from Looss)

Description. Ancylostoma duodenale (Figures 180-181) is characterized by its well developed buccal capsule with two pairs of curved teeth on the ventral wall equal in size, and one pair of dorsal teeth or triangular plates. The body of the living worm is usually white or gray in color and occasionally the posterior two-thirds is bright red due to fresh blood in the intestinal tract.

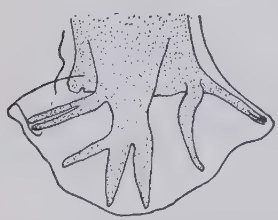


Fig. 183.—*Ancylostoma duodenale.* Side view of bursa. Enlarged. (Redrawn from Looss)

The males measure from 8 mm. to 11 mm. in length by 0.4 mm. to 0.5 mm. in breadth. The dorsal ray in the bursa is divided at its distal end into two smaller rays, which in turn are again divided into three unequal portions (Figures 182-183). The female measures from 10 mm. to 13 mm. in length by 0.6 mm. in breadth. The vulva is situated near the posterior

third of the body. The eggs are elliptical in shape with a transparent shell and when freshly deposited contain two or four and rarely eight blastomeres each. They vary considerably in size, measuring from 56 μ to 60 μ in length by 34 μ to 40 μ in breadth. It is estimated that each female worm produces about 240 eggs per c.c. of formed feces (Augustine et al., 1928).

Position in the host. The adult hookworms inhabit the small intestine where they fix themselves by the mouth to the mucosa. The

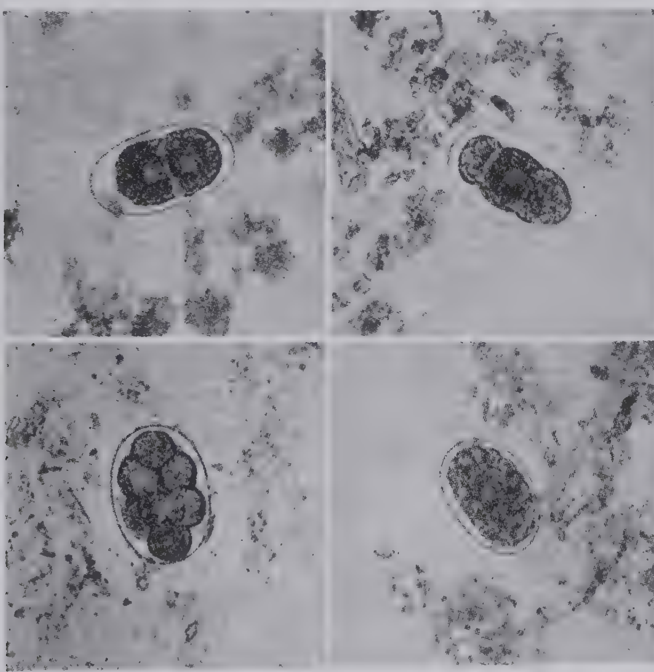


Fig. 184.—Hookworm eggs in different stages of development as found in feces (x 250). (From Todd's *Clinical Diagnosis*, W. B. Saunders Company)

length of life in the intestine is probably about five or six years. *A. duodenale* develops more or less completely in young dogs and cats, but these animals are unnatural hosts for this species and the worms soon die out.

Life-cycle. The eggs laid by the females pass out in the human feces on the soil. The embryonic development is rapid and, under favorable conditions of temperature and moisture, the larvæ hatch out within about twenty-four hours. The newly hatched larvæ

(Figure 185, a) measure on the average 0.25 mm. in length and bear close resemblance to the rhabditiform larvæ of *Strongyloides stercoralis,* but may be differentiated from the larvæ of the latter species by their longer and narrower buccal cavity. The young hookworm larvæ feed on the excrement in which they hatch, and food taken into the body is stored up within the cells of the intestinal tract. By the third day the larva has attained a length of about 0.4 mm. and undergoes its first moult. Growth then continues up to 0.5 mm. to 0.7 mm. when the character of the esophagus changes and becomes slender and filariform in appearance. The second moult occurs at this time and the larva becomes the infective organism (Figure 185, b). The old skin may either be retained or shed depending largely on the physical character of its immediate environment. Further growth and nutrition ceases unless this larva successfully enters its host.

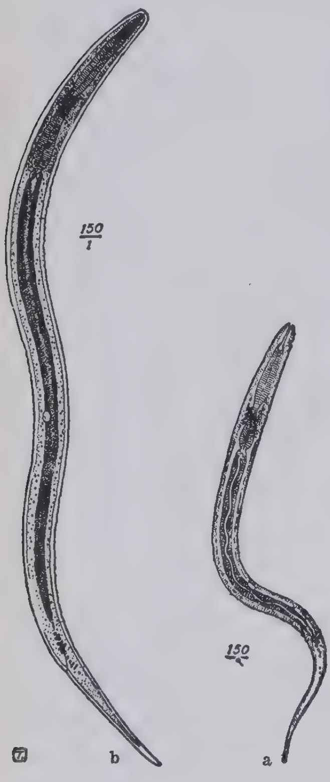


FIG. 185.—*Ancylostoma duodenale.* a, newly hatched or rhabditiform larva; b, mature or filariform larva, the infective stage. (From Manson-Bahr's *Manson's Tropical Diseases.* Partly after Looss)

The infective hookworm larvæ may be taken into the body with drinking water or contaminated food, but their usual method of entrance is by boring through the skin and entering the lymphatics or veins and they are then passively carried by the blood to the heart and thence to the lungs. They break out of the alveolar capillaries into the pulmonary alveoli and crawl up the bronchi and trachea and are finally swallowed. They then pass down the esophagus through the stomach to the intestine where they undergo a third moult within four or five days. The fourth or last moult occurs after about the thirteenth day, at which time the worm acquires its adult characteristics. Ova appear in the feces in from three to four weeks after infection.

Biology of the free-living stages. Very little accurate information was available on the life of the free-living stages of hookworms until

Baerman (1917) devised a simple method by which nematodes could be isolated from considerable quantities of soil. With this apparatus it has been possible to study the activities of the developmental stages in their natural environments and to determine exact sources of human infection. The methods of counting helminth eggs in feces, as devised by Stoll (1923) and the Caldwells (1926) have placed ? experimental studies on the biology of the free-living stages on a definite quantitative basis. The following discussion is based largely on the researches of Cort and his associates carried on from 1921 to 1926 in the West Indies and China. In most instances these observations were made on *Necator americanus*. Comparative studies on *A. duodenale* and closely related species have shown, however, that the requirements for development and the habits of the free stages of this species are practically identical with those of *N. americanus*.

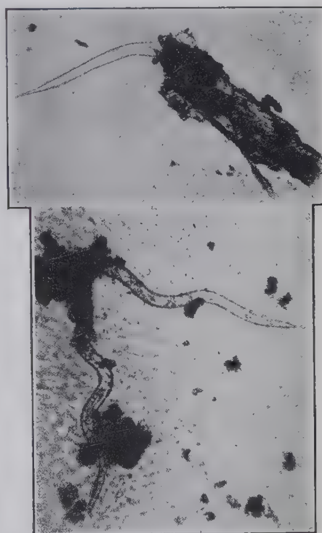


Fig. 186.—*Necator americanus.* Upper photograph showing sheath of a filariform larva cast when the larva penetrated vegetable débris; lower photograph, sheath cast in a sticky clay soil.

In all countries where hookworm is prevalent the people are more or less primitive and unaccustomed to sanitation. They habitually defecate on the surface of the ground, usually in an area which is in some way more or less protected from view, such as in coffee or banana groves, corners of cultivated fields, corners of houses and along the sides of roads or paths. In time certain of these places become well defined defecation areas. Hookworm eggs, as well as the later developmental stages, are not capable in themselves of leaving the area in which they were deposited by the host and, unless they are mechanically carried to other areas by outside forces, they develop at that spot to the infective stage, providing the physical conditions are favorable. Domesticated animals frequently are given a wide range and in one way or another may be factors in hookworm dissemination. Ackert and Payne (1921) demonstrated that when human stools containing hookworm eggs are eaten by pigs, the eggs pass through this animal unharmed and may subsequently develop into normal infective larvæ, but that a high proportion of the eggs

devoured by chickens are destroyed, presumably by grinding in the gizzard. Chandler (1924) showed that hookworm eggs devoured by dogs and rats were uninjured by passage through the digestive tract of these animals. As these animals feed to a great extent on human feces in many tropical countries, they may be of considerable importance in the spread of hookworm eggs.

Conditions influencing the development of the larvæ. The temperature, moisture and the nature of the soil are the most important factors in the development of the hookworm larvæ. Temperature and moisture conditions of the tropical and subtropical countries are usually optimum for a greater or less portion of the year for hookworm development. The nature of the soil has an important influence on the degree of development and may be the determining factor in the incidence and intensity of hookworm infection in areas otherwise favorable. Heavy clay soils are unsuitable for the development and survival of hookworm larvæ, whereas light, sandy or alluvial soils are favorable, and it is on such soil that hookworm infection is most frequent and most severe. Hookworm eggs do not develop under water, presumably on account of the exclusion of oxygen, and it is for this reason that the infection is light or absent in extensive rice producing areas (Cort et al., 1926).

The position of hookworm larvæ in the soil. The first or rhabditiform larva is a feeding stage, and it is usually found near its supply of food, the feces of the host or decaying organic matter. When it develops into the filariform or the infective larva it no longer feeds, and acquires tropisms which are characteristic of this stage. Its chief and only purpose is to carry the infection back to the host. The infective larvæ migrate in a vertical plane to the very top soil particles from which they extend themselves, singly or in polyp-like masses with the support of the surface film of soil water. So dominant is the upward movement that the larvæ remain practically at the spot where the infected feces were deposited, unless disseminated by outside agencies, animals, or washing rains, and for this reason a particular spot may contain thousands of infective hookworm larvæ whereas another spot one foot away may be entirely free of them. This position of the infective larvæ in the soil is most advantageous to them in their transfer to the naked foot of man as he walks on the infected ground.

The infective larvæ are markedly thermotropic, and when transferred to the naked foot or other exposed parts of the body, their activity is greatly aroused and almost immediately they begin boring into the skin. Entrance is usually made by way of the hair follicles,

but they can bore into any part of the skin as well. Damp soil clinging to the feet is an aid to the larvæ in penetrating the skin, for it not only keeps them moist but also helps keep the larvæ tight against the skin.

Length of life of infective hookworm larvæ. Unless the infective larva successfully enters man its length of life is limited by the supply of food stored in its intestinal cells, providing other factors are favorable. In water, under laboratory conditions, they have been kept alive for as long as eighteen months (Nicoll, 1917; Ackert, 1924). In the soil, however, under natural conditions, frequent droughts, changing temperatures, heavy rains, natural enemies such as bacteria, protozoa and fungi are continually acting upon the larvæ and their numbers become greatly reduced within a short time. A few of a given lot may survive for several months, but it is doubtful if these have sufficient vitality to gain entrance to their host when such an opportunity presents itself (Ackert, 1924). The death-rate of a given lot of larvæ is always greatest within the first ten days. The unsheathed forms are less resistant to adverse conditions and are the first to succumb.

Hookworm disease, treatment and prevention. See pages 399 to 408. here

(2) Ancylostoma braziliense de Faria, 1910. This parasite is commonly found in certain wild and domestic animals, particularly dogs and cats in various countries including the southern United States, Brazil, the Federated Malay States, the Philippine Islands and the Fiji Islands. It has been found a parasite, in the adult stage, in man in the Orient, and recently its infective larval stage has been discovered to be the cause of a "creeping eruption" in man in Florida by White and Dove (1928) (see page 406). This species is smaller than *A. duodenale* and the internal pair of ventral teeth are much smaller than the corresponding teeth of *A. duodenale.* The outer cusps are large and end in a very sharp point. The egg is not distinguishable from those of other hookworms in man.

Fig. 187.—*Ancylostoma braziliense.* Showing characteristics of mouth parts. (After Looss)

(3) Ancylostoma caninum Ercolani, 1859. This species is common and practically cosmopolitan in the dog and cat. It is particularly frequent in young animals and prenatal infections are not

unusual. It is the cause of a serious disease in these animals and in some parts of this country it is responsible for the death of from 25 per cent to 40 per cent of the puppies born (Stiles, 1903). It is of about the same size as *A. duodenale* but has three pairs of teeth on the ventral surface of the buccal capsule, whereas *A. duodenale* has two pairs.

2. SUBFAMILY NECATORINÆ Lane, 1917

ANCYLOSTOMIDÆ with the anterior margin of buccal capsule usually bearing ventral cutting plates but without teeth. The mouth is directed antero-dorsally. Example: *Necator americanus* in man.

(1) NECATOR AMERICANUS (Stiles, 1902). *Historical. Necator americanus* is commonly termed the "New World hookworm" but is perhaps as much an "Old World" species as *Ancylostoma duodenale*. It was probably introduced into America from Africa by slaves. The disease in the United States caused by this species was long recognized before the worm itself was discovered. Pitt in 1808 ascribed dirt-eating and anemia (now recognized symptoms of hookworm disease) then prevalent among the lower class negro and white population of the southern United States to deficiency in nourishment. Similar symptoms were described in slaves in Jamaica by Thomas in 1820.

The first reported case of hookworm disease in the United States is that of Blickhahn (1893) of St. Louis. The infection in this case was, however, probably with *Ancylostoma duodenale* as the patient was a brickmaker from Westphalia. Soon endemic cases were noted, especially in Texas, and from 1896 on an increasing number of cases were reported from different parts of the country and it was soon noted that the infections were with a heretofore undescribed species of hookworm.

This species was described as *Uncinaria americana* by Stiles in 1902, from material received from A. J. Smith and T. A. Claytor in the United States and from Ashford in Porto Rico. Stiles showed that this parasite was widely distributed throughout the Southern States and pointed out the great burden of hookworm disease on a large part of the southern population. Ashford in 1899 (Ashford and Gutierrez, 1911) recognized these worms as a cause of anemia in Porto Rico but thought the species was *Ancylostoma duodenale*. It will be recalled that hookworms had also been noted much earlier in Brazil, but a species difference was not observed.

Distribution and frequency. Necator americanus, like *A. duodenale,* is largely confined to the tropical and subtropical world. It is frequently found in mixed infections with *Ancylostoma.* It is particularly prevalent in southern North America, Central and South America and throughout the West Indies. It is the only adult hookworm thus far known to occur in man in the southern United States and, according to Chandler (1928), it is about the only hookworm of man in southern India.

N. americanus, like *A. duodenale,* is typically a parasite of rural populations where little or no sanitation exists, and where temperature, moisture and soil conditions favor the development of the free-living stages of the parasite. In the United States this species is of economic importance only in the South and Eastern sandy coastal plains and in bordering mountain districts where soil conditions are similar or equally favorable for larval hookworms (Rickard and Kerr, 1926). Within these districts, 89 per cent or more of the children of school age may be found infected and infections with from 500 to 1000 worms are not unusual. Very heavy infection with over 2,500 worms are not infrequent (Augustine and Smillie, 1925).

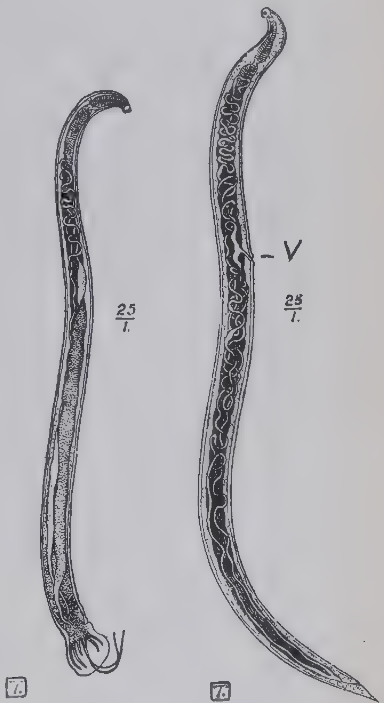


FIG. 188.—*Necator americanus.* Adult male and female. V, vulva. (From Manson-Bahr's *Manson's Tropical Diseases.* After Placencia)

There is a marked difference in the intensity of hookworm infection in white and black races in the southern United States where the two races live side by side on adjoining farms, under very similar economic and sanitary conditions. The infection is generally more frequent and more severe in the white race. While there is as yet no satisfactory explanation for the much lighter infections in the

Negro it may be due to physical differences in the two races, namely the much greater thickness of the epidermis of the Negro which makes more difficult the entrance of infective larvæ, or perhaps to a racial immunity possessed by the black but not by the white race. Further investigations are needed on this point.

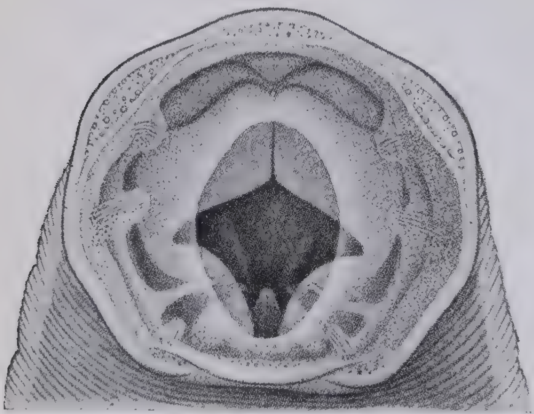


FIG. 189.—*Necator americanus.* Showing cutting plates and the dorsal ridge, and deep in the cavity the edges of the ventral lancets. Enlarged. (After Looss)

It is a well established fact that *N. americanus* produces fewer eggs than *A. duodenale.* According to Stoll (1923) a female *Necator* produces about 9,000 eggs per day, or about forty-four eggs per gram of formed feces.

It is generally believed that the average length of life of the adult *Necator* in the intestine is from four to five years.

Morphology. The mouth capsule of *Necator americanus* (Figure 189) is smaller than that of *A. duodenale* and the two pairs of curved ventral teeth characteristic of the latter species are replaced by a pair of ventral cutting plates. *N. americanus* is also smaller than *A. duodenale.* It is white to grayish-yellow in color and commonly shows blood in the intestine. The male measures from 7 mm. to 9 mm. in length and is about 0.3 mm. in diameter. The dorsal ray of the bursa copulatrix is divided at its base and each branch is bipartite at the tip instead of tripartite as in *A. duodenale* (Figure 190). The female measures from 9 mm. to 12 mm. in length and from 0.3 mm. to 0.4 mm. in diameter. The vulva is located anterior to the middle of the body. The eggs are practically indistinguishable from those of *A. duodenale* (Figure 184). The main points of difference in morphology between *A. duodenale* and *N. americanus* are given in the accompanying table.

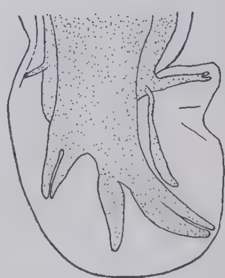


FIG. 190.—*Necator americanus.* Side view of bursa. (Redrawn from Looss)

DIFFERENTIAL CHARACTERS OF ANCYLOSTOMA DUODENALE AND NECATOR AMERICANUS

A. duodenale	*N. americanus*
1. Head continues in same general curve of body	1. Head turned contrary to general curve of body, giving a permanent hooked appearance to anterior end of the worm
2. Buccal capsule with two pairs of hook-like teeth, about equal in size	2. Buccal capsule without teeth but with one pair of cutting plates
3. Vulva posterior to middle of body	3. Vulva anterior to middle of body
4. Small spine at posterior extremity of female	4. No spine at posterior extremity of female
5. Bursa copulatrix fan-shaped	5. Bursa copulatrix more rounded
6. Dorsal ray of bursa tripartite	6. Dorsal ray of bursa bipartite
7. Larger than *Necator*	7. Smaller than *Ancylostoma*

Life-cycle. Shortly after the discovery that the hookworm in America was a new species, investigations were undertaken on its life history and on the disease caused by it. Claude A. Smith repeated Looss' experiments on *A. duodenale* with *N. americanus* and found that infection resulted from skin penetration. Detailed clinical studies were made by Ashford (1911) and his co-workers in Porto Rico. The more recent investigations on the biology of the free-living stages and epidemiological studies include those of Cort, Ackert, Payne, Smillie, Stoll, Chandler and Augustine and have been discussed under the life cycle of *A. duodenale.*

(2) NECATOR SUILLUS Ackert and Payne, 1922. This species was discovered in pigs of Trinidad, B. W. I., where over 89 per cent of these animals are said to be infected. Morphologically it is quite similar to *N. americanus,* but cross infection experiments carried on by Ackert and Payne (1922) indicate that *N. suillus* is a distinct species.

Necator congolensis Gedoelst, 1916, and *N. exilidens* Looss, 1912, have been reported from the African chimpanzee.

(3) HOOKWORM DISEASE. The hookworms feed particularly upon the tissues of the host, and, in tearing bits of the mucosa from the intestine by their powerful mouth parts, produce small hemorrhages at the site of injury (Figures 191-192). The bleeding is maintained by the deposition in the wounds of a poisonous secretion by the hookworms which inhibits the coagulation of the blood. And as the worms change their position again and again and when there are thousands present, the loss of blood from the intestines may be considerable.

It was formerly believed that the marked anemia in hookworm disease was largely due to a hemolytic toxin secreted by the worm. According to De Langen and his co-workers (1923), the toxic factor has no hemolytic influence on the red blood cells of the host but it exercises a disturbing influence on the different organs,

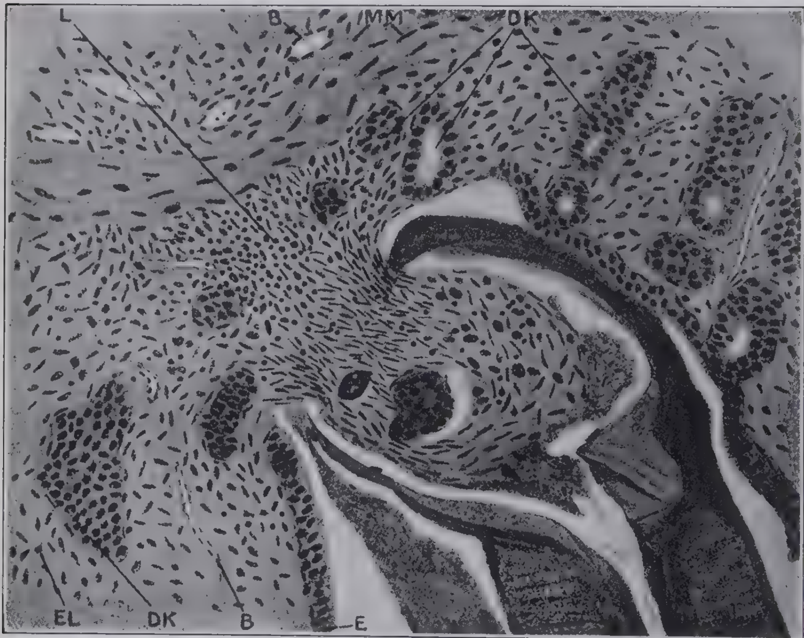


FIG. 191.—A sagittal section of the head end of a hookworm, *Ancylostoma duodenale*, grasping a piece of mucous membrane, L; EL, eosinophile leucocytes; DK, intestinal glands; B, blood vessels; E, epithelial cells. Enlarged. (After Oudendal)

particularly the blood-producing organs, the bone marrow, and thus causes the anemia.

A severe hookworm dermatitis frequently results when the infective larvæ pass through the skin which is locally known as ground itch, mazamorra, water sores or sore feet of coolies. This dermatitis is most frequent in the rainy season in the tropics and during the spring and summer months in the southern United States when moisture and temperature conditions are at the optimum for larval development. It occurs most frequently on the feet, particularly between the toes, for it is these parts which are constantly exposed to the

larva-laden earth. Vesiculation and pustulation or even ulceration often result which may persist for several weeks.

Symptoms. Hookworm disease is characterized by a more or less severe anemia and faulty development. The skin takes on a light orange-yellow coloring which first arises in the temples and later on extends over the whole body. The patient has a typical apathetic expression (Figures 193-194), and is often undersized, with dry skin, scanty hair, edema of the face and legs, shortness of breath and weakness with his mental development retarded.

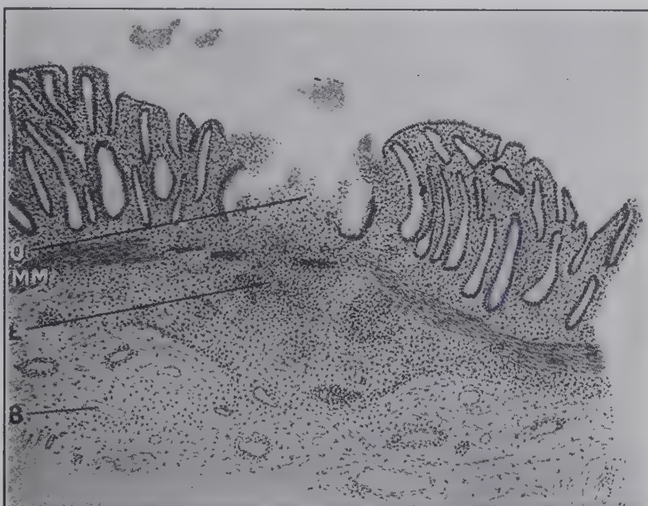


FIG. 192.—Diagonally cut section of the intestine showing an ulcer caused by *Ancylostoma duodenale.* U, ulcer; MM, muscularis mucosæ; L, lymphocytes; B, blood vessels. Enlarged. (After Oudendal)

All individuals showing hookworm ova in their feces do not, however, show characteristic symptoms. This is in part due to differences in individual resistance and to the number of worms harbored. As shown by Smillie and Augustine (1926) children with twenty-five *Necator americanus* show no measurable injuries and are apparently as healthy and alert as individuals free from hookworms and therefore may be regarded as carriers. Children with from twenty-six to 100 hookworms, *N. americanus,* show no variation from the normal in rate of growth in weight and height but may have slightly lowered hemoglobin and slight mental retardation. Many individuals in this

group are borderline cases and may be classed among those with mild hookworm disease. Children with more than 100 hookworms, *N. americanus,* however, usually show marked retardation in normal growth in height and weight, a more or less severe anemia, and may show a marked degree of mental retardation (Smillie and Spencer, 1926). This group is regarded as having true hookworm disease. It is generally believed that *A. duodenale* is more malignant than *N. americanus* and that relatively few worms of the former species may cause a definitely diseased condition.

FIG. 193.—Typical facial expression of individuals suffering from hookworm disease. (From Ashford and Gutierrez)

Treatment. Thymol was tried by Bozzolo in 1879 as a vermifuge for hookworm anemia among the bricklayers in northern Italy and has since been used extensively for this purpose. Thymol, however, is not a very safe drug, as it is very soluble in alcohol and various oils, and it has been almost replaced recently by oil of chenopodium or ascaridol, and carbon tetrachloride. Hall and Shillinger (1925) have found tetrachlorethylene an efficient anthelmintic against the hookworm. This drug appears to be less toxic than carbon tetrachloride (Hall and Augustine, 1929).

Oil of chenopodium: The preparation should contain at least 70 per cent of ascaridol, the active anthelmintic principle of oil of chenopodium. No preliminary purge is necessary. The maximum adult dose is 1.5 c.c., according to Tyzzer and Smillie (1927), with treatment as follows:

6 A.M. Administer one-half the dose of oil of chenopodium in hard gelatin capsules on an empty stomach.
8 A.M. Administer second half of the dose.
9 A.M. Administer one ounce of magnesium sulphate in full glass of water.

A soapsuds enema should be given in two hours if the bowels have not acted within that time.

The dose should be carefully graduated for children according to age and size.

Dizziness, nerve incoordination and more or less severe burning sensation in the palms of the hands and on the soles of the feet often follow the administration of oil of chenopodium. These symptoms usually disappear shortly after the first bowel movement.

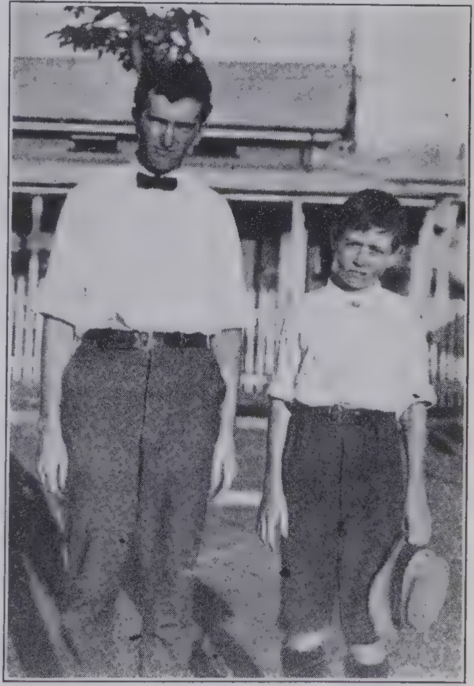


FIG. 194.—Showing the effect of hookworm disease on growth. Left, boy of eighteen years, hookworm free; right, boy of nineteen years, heavily infected with hookworms. (Photograph by permission of the Rockefeller Foundation)

Carbon tetrachloride: Carbon tetrachloride was first reported by Hall (1921) as an anthelmintic in veterinary medicine and was later brought to the attention of physicians by him as of possible value in removing hookworms from man. Since that time this drug has been used extensively in human medicine, especially in the hookworm campaigns of the International Health Division of the Rockefeller

Foundation. It has been found to be a very effective and comparatively safe anthelmintic. The chief contraindication is alcoholism. The adult dose for man is 3 c.c. on an empty stomach at 7 A.M. and followed in two hours by a purge of magnesium sulphate.

Mixed treatment with oil of chenopodium or ascaridol and carbon tetrachloride are regarded as highly effective and safest for hookworm disease in man. Three parts of carbon tetrachloride to one of oil of

Fig. 195.—Group assembled to hear a public health lecture and receive treatment for hookworm disease, Colombia, S. A. (Photograph by permission of the Rockefeller Foundation)

chenopodium or ascaridol is recommended by Tyzzer and Smillie (1927) and administered as follows:

7 A.M. Administer 1.5 c.c. carbon tetrachloride on an empty stomach.
8 A.M. Give 0.5 c.c. ascaridol or 0.75 c.c. of oil of chenopodium.
9 A.M. Magnesium sulphate, 30 gms.
The dose should be correspondingly reduced for children.

Prevention. Since the spread of hookworm disease in due entirely to neglect of sanitation, its prevention and control requires the installation of adequate latrine accommodations and the habitual use of them by the people who are to be directly benefited. Anthelmintic treatment relieves immediate suffering, but without sanitation reinfection occurs and the benefit from the anthelmintic is only transient. Proper disposal of human feces and the education of the people as

to the mode of transmission are the chief measures of permanent control of hookworm infection.

It was formerly thought that infection might commonly result from water or food contamination with infective larvæ but these are now known to be unimportant sources of infection, and it is highly

FIG. 196.—Besides getting rid of his hookworms this boy also became free of his ascarids after one treatment with oil of chenopodium. (Photograph by permission of the Rockefeller Foundation)

probable that each parasite in the intestine has entered through the skin. Therefore shoes, even though of crude design, are more or less effective in preventing the entrance of the larvæ. This protection is clearly shown in comparing the hookworm incidence in relation to age in Brazil and in Alabama, which is believed to be typical for all of the southern United States (see Chart I). The two curves of this

chart correspond closely until the 16-17 age period, when the Alabama curve reaches a maximum followed by a rapid decrease in intensity. The Brazilian curve reaches its maximum at about twenty-four years, and then remains quite constant for a long period. The remarkable decrease of hookworm intensity in Alabama children is due to the custom of beginning the constant use of shoes at about fourteen years, for little or no new infection is then acquired, and the old parasites gradually die out in from three to five years.

(4) Creeping Eruption. The names creeping eruption, *Larva migrans,* dermatitis linearis migrans and creeping disease, have gen-

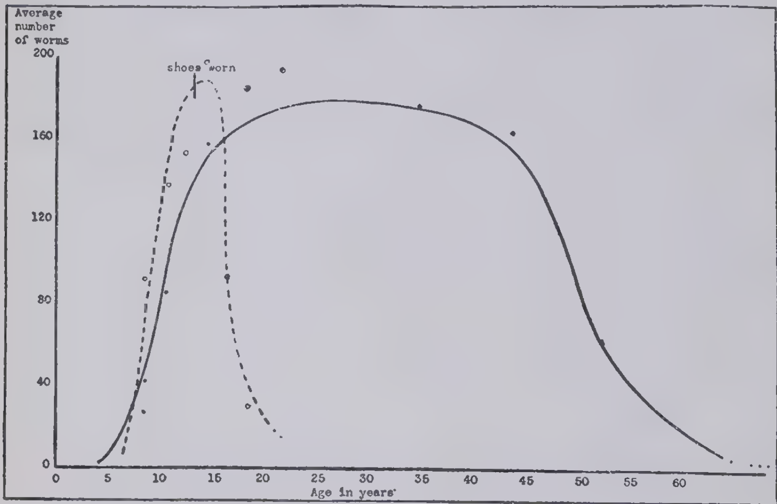


Chart 1.—Hookworm incidence in relation to age, comparing Brazil and Southern states of North America: solid line, Brazil; broken line, Southern States.

erally been associated with skin lesions caused by various fly larvæ and by a nematode, *Gnasthostoma spinigerum.* Recently Kirby-Smith, Dove and White (1926) and Dove and White (1926) have demonstrated that this disease may be caused also by the infective larvæ of *Ancylostoma braziliense,* a rather frequent parasite of dogs and cats. The eruption is exceedingly prevalent in the southern United States, especially in Florida. Dr. Kirby-Smith has conservatively estimated that he has seen not less than 2,500 cases during his fourteen years' practice of dermatology in Florida. It is characterized by a linear, tortuous and serpiginous eruption due to the larva migrating within the skin and is accompanied by intense itching. The most recent lesion

caused by the worm is indicated by a very narrow reddish line which later becomes slightly raised and palpable. The surface then becomes dry and a thin crust is formed. According to Kirby-Smith and others (1926) the parasite may travel from a fraction of an inch to several inches a day, advancing as a rule more rapidly at night. Scratching to alleviate the itching often results in bacterial infections and raw surfaces. About 50 per cent of the cases seen by Dr. Kirby-Smith are believed to have originated at the beach at points above the high tide water mark. Several cases definitely attributed the origin of their infection to contact with damp sand when they were wet with perspiration and while working in the sand in repairing automobiles or making plumbing connections underneath houses. Creeping eruption most frequently occurs during the summer months following periods of rainy weather, which is to be expected in view of our knowledge of the development of the free-living stages of the hookworms. The infection may persist for a very long time; Fülleborn (1926) has reported one case of twenty years' duration.

Treatment. Ethyl acetate applied on cotton or gauze or used in a flexible collodion has been found effective in many cases, as well as refrigeration with ethyl chloride, carbon dioxide snow or crushed ice with salt. Dakin's solution (chlorinated soda) may be employed for the secondary infections which are frequently associated with creeping eruption.

Prevention. Prophylactic measures taken against "ground itch" are equally effective against creeping eruption caused by the infective larvæ of *A. braziliense*. As this hookworm is a natural parasite of dogs and cats, frequent anthelmintic medication of these animals would greatly reduce soil infection and thereby render less likely the infection in man. All stray dogs and cats should be disposed of.

(5) Bunostomum trigonocephalum Rudolphi, 1808. This hookworm is a frequent parasite in the small intestine of sheep and goats in Europe and the southern United States. The male is from 12 mm. to 17 mm. in length and the female is from 19 mm. to 26 mm. in length. A closely related species *B. phlebotomum* Railliet, 1902, occurs in cattle and has been associated with the so-called "salt sickness" of Florida. This disease is characterized at first by low fever, loss of appetite and progressive emaciation and anemia.

(6) Uncinaria polaris Looss, 1911. *Uncinaria polaris* appears to be a fairly frequent parasite of foxes in North America and may prove to be of considerable economic importance in the fox-raising industry. The male measures about 8 mm. and the female about 11 mm. in length. *U. criniformis* (Rud. 1809) or *U. stenocephala*

Railliet, 1884, is a somewhat smaller species which has been repeatedly noted in European foxes and dogs. Apparently this latter species does not exist in this country.

III. *Family Metastrongylidæ* Leiper, 1908

STRONGYLOIDEA with the buccal capsule much reduced or absent. The bursa of the male may be relatively well developed or vestigial with more or less typical rays. The METASTRONGYLIDÆ are parasites of the respiratory and circulatory systems of mammals. Examples: *Dictyocaulus filaria* in sheep and goats, and *Metastrongylus apri* in the pig

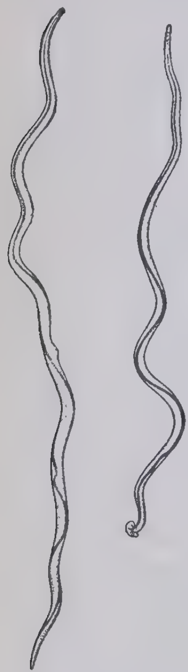


FIG. 197.—*Dictyocaulus filaria*, male at right, female at left. Highly magnified. (From Hall. After Curtice)

1. DICTYOCAULUS FILARIA (Rudolphi, 1809).

Description. Dictyocaulus filaria (Figure 197) is commonly known as the "thread lung worm" and is found in the air passages, bronchi and bronchioles of the lungs of sheep, goats, cattle and other ruminants. It is a rather long worm, the male measuring from 3 cm. to 8 cm. and the female from 5 cm. to 10 cm. in length. The intestine shows as a dark hair-line throughout the length of the worm. The eggs are elliptical and vary from 112 μ to 135 μ in length by 52 μ to 67 μ in breadth and contain a fully developed embryo at the time they leave the female worm.

Life-cycle. The eggs hatch in the lung of the host and the first larvæ leave the lungs by way of the trachea and get onto the pasture either in the saliva or in the feces. This larva moults twice within a short time, according to temperature and moisture conditions, and in about ten days it is in the infective stage. The infective larva crawls up grass blades when they are wet and is then taken in by grazing sheep or cattle and eventually makes its way to the lungs where it grows to maturity.

D. filaria is widely distributed over the world and is fairly common in the United States, especially in our Southern States where climatic conditions are more favorable for the development of the free stages.

Pathogenesis. The presence of the worms and their eggs and

larvæ may set up an irritation of the lung tissue at the point at which they are located causing a catarrhal condition, and bacterial infection of the weakened lung may follow. Infected animals usually show larvæ in saliva taken from the back of the tongue or from the pharynx.

D. arnfieldi (Cobbold, 1884) is parasitic in bronchi of horses and other EQUIDÆ.

Prevention. Segregation of infected animals and pasture rotation are of value.

2. SYNTHETOCAULUS RUFESCENS (Leuckart, 1865)

This species occurs in the small bronchioles and in the lung tissue of sheep, goats and rabbits and is commonly termed the "hair lung worm." It is a smaller worm than *D. filaria* and the body has a characteristic brownish-red color, due to the color of the intestine. Its life history is not definitely known, but it is probably similar to that of *D. filaria*. The hair lung worm is widely distributed but is apparently less common in the United States than *D. filaria*. Infections with this species may terminate in a verminous pneumonia. When the worms are aggregated in the pneumonic areas they may cause a pneumonia with areas resembling tubercles. These show as grayish-yellow tumors from a few millimeters to two centimeters in diameter in which are the reddish worms, eggs and embryos. Secondary bacterial infections sometimes occur.

S. obstrusus Railliet, 1898, is parasitic in the lungs of the cat.

Metastrongylus apri Gmelin, 1790, is a fairly common parasite of bronchi of pigs and wild boars and very rarely occurs in man. *Hæmostrongylus vasorum* (Railliet, 1866) occurs in the heart, pulmonary arteries and in the eyes of the dog.

IV. *Family Trichostrongylidæ* Leiper, 1912

STRONGYLOIDEA with a rudimentary buccal capsule, or the buccal capsule may be absent. The bursa copulatrix has well developed lateral lobes but with the dorsal lobe small or rudimentary. The members of TRICHOSTRONGYLIDÆ are for the most part parasites of lower animals, ruminants and herbivores, and their occurrence in man is more or less accidental.

This family includes two subfamilies: (1) The TRICHOSTRONGYLINÆ Leiper, 1908, and (2) the HELIGMOSOMINÆ Travassos, 1914. The members of HELIGMOSOMINÆ are of no economical importance,

and are, for the most part, parasites of rodents. They are slender forms with the buccal capsule absent or rudimentary and the female reproductive system consists of a single tube. The vulva is situated close to the anus. As far as we know their development is direct and similar to that of the hookworms. *Heligmosomum muris* Yokogawa, 1920, in wild rats of the United States is a representative species.

The TRICHOSTRONGYLINÆ differ from the HELIGMOSOMINÆ in that the female genital tubes are paired. The vulva is situated towards the posterior end of the body. The development is probably direct in all species.

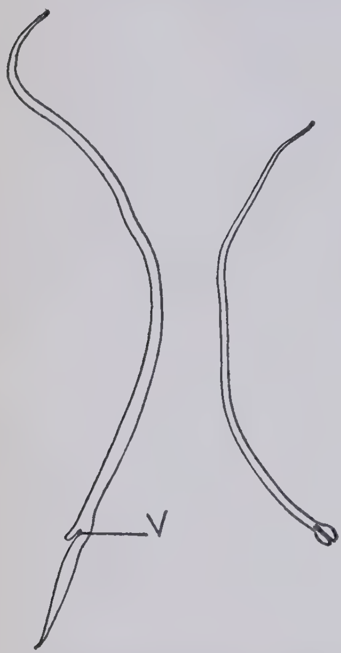


FIG. 198.—*Hæmonchus contortus.* Right, male; left, female. V, vulva. Magnified five times. (After Ransom)

I. HÆMONCHUS CONTORTUS (Rudolphi, 1803)

Description. A number of strongyles are parasites in the abomasum, the fourth or digestive stomach and in the duodenum of ruminants. Certain of these species are of considerable economic importance, particularly HÆMONCHUS CONTORTUS. This parasite (Figure 198) is whitish or of a reddish color which is attributed by most authors to blood which it has sucked up. Two lateral, toothlike papillæ are situated near the anterior end of the body. The male is from 1 cm. to 2 cm. in length and the bursa copulatrix consists of two long lobes and an accessory right lobe. The female is from 2 cm. to 3 cm. in length and has a spiral striping. The vulva is situated in the posterior fifth of the body and is marked by a more or less prominent linguiform process which projects backward. The eggs are elongated, oval and measure from 75 μ to 95 μ in length by 40 μ to 50 μ in breadth and are segmenting when deposited.

Life-cycle. The development is direct. The infective stage is a sheathed larva. It crawls up wet grass blades and here becomes ingested by grazing sheep and cattle. They are highly resistant forms

and can withstand severe cold and long periods of dryness. The eggs and first larvæ are, however, less resistant.

Distribution. H. contortus is world-wide in distribution, occurring wherever there are sheep, cattle or other suitable host animals. It has been reported once as a parasite of man in Brazil.

Pathogenesis. This species is very injurious to sheep, especially when occurring in large numbers. It evidently feeds upon the blood of its host, attacking the mucous membrane of the abomasum. The infected animals become dull and anemic showing emaciation and irregularities of digestion. Diarrhea may be present.

The genus *Trichostrongylus* Looss, 1905, contains several species which are common and important parasites in the small intestine of sheep and cattle, and rarely in man. *T. probolurus* (Railliet, 1896); *T. colubriformis* (Gilles, 1892); and *T. vitrinus* (Looss, 1905), occur in sheep and goats and have been reported in man. *T. orientalis* Jimbo, 1914, occurs as a parasite of man in Japan, Korea, and Formosa. *T. extenuatus* (Railliet, 1898) is a common and widely distributed parasite of ruminants in the United States and is considered by some authors to be a cause of gastro-enteritis in calves. *T. capricola* Ransom, 1907, occurs in goats and sheep of the United States and is apparently a more frequent parasite in these animals than *T. extenuatus.*

Of rarer occurrence are several species of the genera *Ostertagia* Ransom, 1907, and *Cooperia* Ransom, 1907.

2. NEMATODIRUS FILICOLLIS (Rudolphi, 1802)

The nematodes of the genus *Nematodirus* are commonly termed the "thread-necked strongyles" on account of the anterior portion of the body being more slender than the posterior. They are found in the small intestine of sheep and cattle. *N. filicollis* occurs in the small intestine of sheep, cattle, goats and other ruminants and is of rather common occurrence in the United States but usually not in large numbers. It therefore probably does not seriously affect its host Attention is again called to the fact that the infective larva of *N. filicollis* develops within the egg before hatching, thus differing from other forms such as the hookworms and *H. contortus,* in which the first larva hatches and, after a feeding stage, develops in the open into the filariform or infective larva.

Treatment. Copper sulphate and sodium arsenate in the proportion of 4 to 1 have been used effectively against *H. contortus* and

other "stomach worms" of sheep. According to Hutyra and Marek (1926) the dose is 0.625 gm. for adult sheep, 0.5 gm. for yearlings, 0.375 gm. for lambs six to ten months old, 0.25 gm. for lambs four to six months old, and 0.2 gm. for lambs two to four months old, given on the empty stomach. Carbon tetrachloride in doses of 10 c.c. followed immediately by 128 gms. of magnesium sulphate, according to Hall and Shillinger (1925) is highly effective in removing stomach worms, *Hæmonchus contortus,* nodular worms, *Esophagostomum* sp. and small trichostrongyles, *Ostertagia* sp., from sheep and is especially effective against the blood-sucking *Nematodirus* sp.

Prevention. Pasture rotation is essential. Cattle and sheep should be kept out of each pasture for at least one year before it is used again. Young animals are most susceptible to the infection and should therefore be furnished the safest pasture lands. Frequent anthelmintic treatment is advised.

CHAPTER XXVIII

THE ORDER FILARIOIDEA

The FILARIOIDEA are parasitic nematodes with paired lateral lips, or with or without prominent lip-like structures. The esophagus is without a bulb but is divided into a muscular anterior portion and a glandular posterior portion. The eggs are embryonated when laid or may hatch within the uterus. They differ from other nematodes previously studied in that they require an intermediate host for development and transmission.

This order, according to Baylis and Daubney (1926), is made up of six families: (1) FILARIIDÆ Claus, 1885; (2) PHILOMETRIDÆ Baylis and Daubney, 1926; (3) SPIRURIDÆ Örley, 1885; (4) CAMALLANIDÆ Railliet and Henry, 1915; (5) CUCULLANIDÆ Barreto, 1916, and (6) GNATHOSTOMIDÆ Railliet, 1895, all of which contain species of medical importance.

I. *Family Filariidæ* Claus, 1885

FILARIOIDEA with usually filiform and much elongated bodies. The females are not more than three or four times as long as the males. The head is characterized by two lateral and four submedian papillæ, and the mouth is usually without lip-like structures. There are usually two spicules, dissimilar and unequal. The vulva is almost always in the esophageal region. The adults inhabit the connective tissue, blood-vessels or serous cavities of vertebrates.

I. SUBFAMILY FILARIINÆ Stiles, 1907

FILARIIDÆ with a simple mouth, not bounded by a chitinous peribuccal ring or epaulette-like structures and without trident-like chitinous structures on each side of the anterior end of the esophagus. The spicules are unequal and dissimilar. The adults are parasites in the connective tissue, blood-vessels or serous cavities of vertebrates. The larvæ produced by the adult parasites are generally found in the circulating blood and are generally known as microfilariæ. As far as

is known, the required intermediate host is either a mosquito or a bloodsucking fly. The FILARIIDÆ infecting man belong to this subfamily. Examples, *Wuchereria bancrofti* (Cobbold, 1877) in man, and *Dirofilaria immitis* (Leidy, 1856) in the dog.

(1) WUCHERERIA BANCROFTI (Cobbold, 1877). *Historical.* This species was known for a long time only in its larval stage in the blood of man. It was first discovered in 1863 by Demarquay in Paris in the hydrocele fluid of a patient from Havana. These larvæ were next observed in 1866 by Wucherer in chylous urine from a number of cases in Bahia, Brazil. Lewis, in 1872, discovered the larvæ in the blood of man in India and found that they were usually present in persons suffering from chyluria, lymphatic enlargements and elephantiasis, and occasionally in apparently healthy individuals. To these larvæ he gave the name *Filaria sanguinis hominis*. The adult was discovered in 1876 by Bancroft in Brisbane and Cobbold gave it the name, *Filaria bancrofti*. Manson in 1878 observed that the microfilariæ were ingested by certain mosquitoes while feeding upon the blood of infected individuals. He later described the metamorphoses of the parasite while within the mosquito's body. Manson also noted the phenomenon of filarial periodicity, and, because the larvæ appeared most frequently at night in the circulating blood, the name *Filaria nocturna* was given them. This larva is now generally referred to as *Microfilaria bancrofti*.

FIG. 199.—*Wuchereria bancrofti*. *a*, male; *b*, female. Natural size. (From Manson-Bahr's *Manson's Tropical Diseases*)

Distribution and frequency. Wuchereria bancrofti is practically world-wide in distribution but, like the hookworms, is largely confined to tropical and subtropical countries. Its dissemination necessarily depends on the extent of the migrations of the infected individual and on the presence or absence of its intermediate hosts. It is especially frequent in India, South China, Samoa and on the Western Pacific Islands. O'Connor (1923) reports that over 61 per cent of the individuals past sixteen years of age in the Ellice Islands show evidence of the infection. The infection is also a very common one throughout the West Indies, in South America and in West and Central Africa. There is one endemic area in the United States, Charleston, S. C. Johnson (1915) found that 19 per cent of the patients admitted to the Roper Hospital in Charleston harbored microfilaria, and Francis (1919) found thirteen, or 35 per cent, of the inmates at "The Old Folks Home" with microfilaria in their blood. It is very probable that the infection was introduced into Charleston,

as well as into other parts of the Americas, by negro slaves from a heavy focus of infection in Africa.

Description. The adult forms of *Wuchereria bancrofti* are white, more or less transparent, thread-like worms with a smooth cuticula. The male is about 40 mm. in length by 0.1 mm. in breadth and possesses two spicules. The larger spicule measures 500 μ in length and has a short, thick proximal portion and a long whip-like distal portion ending with a hook. The shorter spicule is 200 μ in length and is grooved on its ventral surface. A crescent-shaped gubernaculum, or accessory piece, is present. There are fifteen pairs of post anal papillæ. The female measures from 65 mm. to 100 mm. in length by 0.2 mm. to 0.28 mm. in breadth. The anterior end is tapering with the head distinct and followed by a narrower neck. The posterior portion is narrow and ends abruptly rounded. The vulva is situated about 0.6 mm. to 1.3 mm. from the anterior tip. The eggs measure about 40 μ in length by 25 μ in breadth and contain formed embryos when in the upper part of the uterus. The eggs do not possess a true egg-shell but an embryonal covering or vitelline membrane which subsequently becomes the sheath of the living microfilaria (Figure 200).

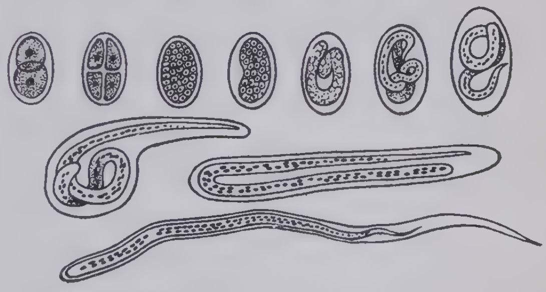


FIG. 200.—Evolution of sheathed microfilaria from ovum in uterus of parent worm. The later stages may occasionally take place after the emission from the vagina. (From Manson-Bahr's *Manson's Tropical Diseases*)

The microfilariæ. In fresh preparations the microfilariæ appear as exceedingly active, thread-like bodies and can be detected with a low power of the microscope as they lash their way among the blood corpuscles. Unless the slide is properly prepared and stained very little definite structure can be determined. After staining with hæmatoxylin a certain amount of structure can be made out (Figure 201). The embryo is enclosed in a sheath which is the stretched out vitelline membrane of the egg. The head is rounded and bears a small spine which may be covered by a six lipped prepuce. The tail is distinctly pointed. The body of the larva is composed mainly of exceedingly small cells. At about one-fifth of the entire length of the body backward from the head is a hyaline V-shaped space which is termed the "V-spot." A smaller, second spot is visible a short distance from

the end of the tail which is known as the "tail-spot." The V-spot probably represents the undeveloped excretory system and the tail-spot the anus or cloaca, as the case may be. There is also a break in the column of nuclei somewhat anterior to the V-spot which indicates the position of the nerve ring.

Periodicity. The microfilariæ of *M. bancrofti* usually appear in the peripheral blood at night, and for this reason they are said to have a nocturnal periodicity. In the Americas, India and China they are found in greatest numbers between ten o'clock in the evening and two o'clock in the morning, while during the day they may be entirely

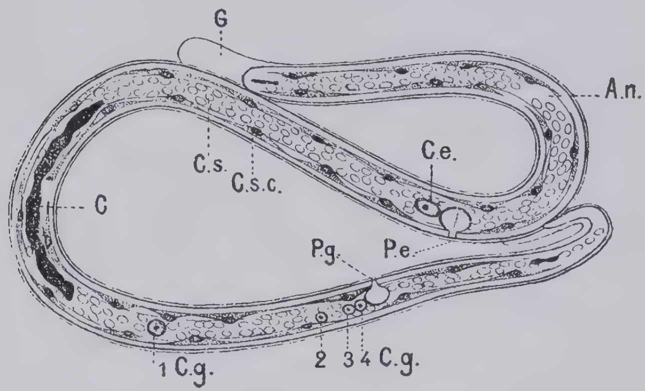


FIG. 201.—Showing detailed anatomy of microfilaria of *Wuchereria bancrofti.* G, sheath; A.n., nerve ring (anterior break in the cell column); C.e., excretory cell; P.e., excretory pore or anterior V-spot; C.s.c., subcuticular cells; C.s., somatic cells; C, granular mass; P.g., anal pore or posterior V-spot; 1, 2, 3, 4, C.g., genital cells (x about 1000). (From Brumpt's *Précis de parasitologie.* After Fülleborn)

absent from the blood. The usual intermediate host for this parasite in the above named countries is the mosquito *Culex fatigans.* This mosquito is a night biting mosquito. In the Philippine Islands and neighboring islands in the Pacific the microfilariæ of *W. bancrofti* do not have a nocturnal periodicity but appear during both the day time and night time in the blood stream in equal numbers. In these islands the usual insect vector is the mosquito, *Ædes variegatus,* which feeds only during the day.

Life-cycle. In order to complete the life-cycle the microfilariæ must be taken up by one of various mosquitoes of the genera *Culex, Ædes,* and *Anopheles.* Of these, *Culex fatigans* and *Ædes variegatus* are the usual intermediate hosts. The mosquito in sucking blood into its stomach takes in the microfilariæ as well. Shortly after entering the mosquito's stomach the microfilaria casts its sheath, pierces the

FIG. 202.—Sausage-shaped larvæ of *Wuchereria bancrofti* teased out of the thoracic muscles of *Culex fatigans*. Magnified. (After Francis)

stomach wall and passes to the thoracic muscles where it comes to lie between the wing muscles and there undergoes metamorphosis. It first assumes a sausage-like form and possesses a rudimentary digestive tract (Figure 202). This larva measures about 0.5 mm. in length. It soon elongates. The digestive tract is completed and three subterminal caudal papillæ appear. At about the tenth day the larva reaches 1.4 mm. in length and travels forward through the thoracic muscles into the proboscis and there lies more or less coiled up and awaits an opportunity to get back into man, which opportunity presents itself when the mosquito again bites an individual. Matured larvæ (Figures 203-204) are occasionally found in the mosquito's head, abdomen, legs, antennæ and palpi but it is doubtful whether any are infective for man unless they are actually in the proboscis. When the infected mosquito feeds upon another individual the larvæ are attracted by the warmth of the body and make their way down the proboscis sheath, the labium. They break through its terminal portion, known as Dutton's membrane, and crawl onto the surface of the host's skin. The larvæ then penetrate the skin at or near the puncture caused by the stilette bundle of the mosquito and pass by the way of the lymphatics to lymph glands where they grow into the adult stage.

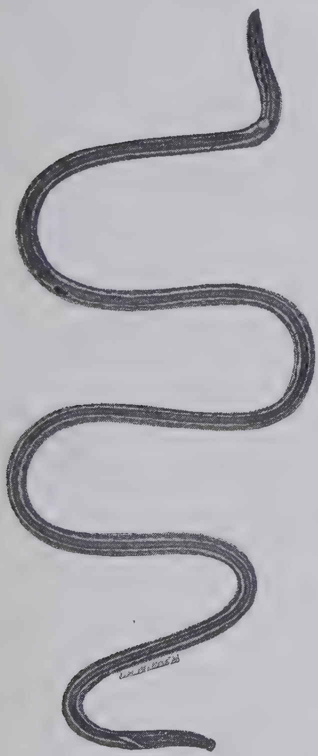


FIG. 203.—Showing structure of mature larva at time of escape from the proboscis of *Culex fatigans*. Magnified. (After Francis)

While the mosquito is the sole agent in the transmission of *Wuchereria bancrofti,* as in the transmission of malaria, the trans-

mission is accomplished with much less certainty and promptness in the case of filariasis than in malaria. There is no multiplication of the filaria larvæ in the intermediate host. There develops but one infective larva from each microfilaria sucked in by the mosquito whereas the malaria parasite multiplies enormously in the mosquito and the chance of the infection being returned to man is by thousands of times more likely. The actual number of microfilariæ sucked up by the mosquito is also relatively small in comparison with the number of malarial organisms in the blood which may be taken up in a similar manner. A high mortality may also occur among the microfilariæ which actually reach the stomach of the mosquito. At every

FIG. 204.—Mature larva of *Wuchereria bancrofti* migrating through the labium of *Culex fatigans.* Magnified. (After Sambon)

step of the transmission of *W. bancrofti* by the mosquito only a small number are involved. Conjugation of the sexes is essential to multiplication and that conjugation takes place only within the lymphatic system by the adult worms. When the infective larva leaves the proboscis of the mosquito it is of one sex or the other and, although it may successfully become established in a lymph gland, multiplication can not take place until one of the opposite sex lodges within that same lymph gland. It is therefore possible that an individual might harbor a relatively large number of adult parasites and yet show no microfilariæ in his blood because the adults are so distributed that the two sexes never meet. It is quite evident that successful infections are only the result of mass biting by mosquitoes and the spotted geographic distribution of this and related species is due to these factors.

Pathogenesis. It is generally held that the microfilariæ are not pathogenic but that serious disorders may in some way be brought about by the adult worms, and these disorders in every case can be

traced to interference with the lymphatic system. It is generally stated that the adult worms may obstruct the thoracic duct or occlude the smaller lymphatic vessels or the lymph glands resulting in a damming up of the lymph and thus giving rise to a lymph edema. Lymphangitis, abscess, hydrocele, lymph scrotum, chyluria and elephantiasis of the leg, scrotum, vulva, arm and breast are among the more serious consequences of the infection (Figure 205).

Fig. 205.—Elephantiasis of lower limbs. (From photograph by Sambon)

Anderson (1924) believes that the worms may irritate or damage the interior of the lymphatics and the fine internal structure of the glands, and thus prepare the way for bacterial invasion, and that the pathological manifestations associated with filariasis are due to secondary infection with these organisms. The observations of O'Connor (1923) on early signs and progress of the infection bear evidence that the clin-

ical symptoms are due to the presence of the worms alone. O'Connor observed that microfilarial incidence in the western Pacific Islands is in direct relation to the prevalence of *Ædes variegatus,* that the incidence of clinical filariasis is in direct relation to the microfilarial incidence, and that elephantiasis is usually prevalent where clinical filariasis is greatest.

The diagnosis of infections with *W. bancrofti* is made by finding the characteristic microfilariæ in the blood. Many cases however showing clinical symptoms show no microfilariæ in blood nor in the contents of the dilated vessels. In such instances the infection is usually of long standing and either the adult worms have died or the lymphatics draining the affected area have become completely obstructed by the worms and their products to such an extent that the microfilariæ cannot pass along the vessels to enter the circulating blood.

Treatment. Thus far no satisfactory medical treatment for filariasis has been perfected but Anderson (1924) has noted improvement in septic conditions after injections of specific vaccines. Elephantiasis of the scrotum and breast may be successfully treated by operative measures.

Prevention. In view of the fact that *W. bancrofti* is transmitted to man solely through bites of mosquitoes, its prevention is primarily one of mosquito control and measures taken against mosquitoes in malaria and yellow-fever control are equally effective against this parasite. *Culex fatigans* is a domestic mosquito and breeds in cisterns, rain barrels, and tin cans. *Ædes variegatus* also breeds in fresh water in the husks and shells of cocoanuts, in crevices and holes in trees, bottles and tin cans. O'Connor (1923) has observed that the Pacific rat makes breeding places for *Ædes* in trees by gnawing and gutting the young cocoa-pods. These pods become dry and soon form hanging reservoirs.

(2) Loa loa (Guyot, 1778). *Historical. Loa loa* is commonly known as the eye worm of West Africa. It was noted as early as 1598 by Pigafetta during his travels on the Congo. It was later observed by Guyot, a French ship's doctor while cruising the West Coast of Africa and it was known by the name "loa" among the natives. *L. loa* is said to have been of common occurrence among the negroes in South America during slave days but disappeared when the slave traffic ceased, apparently because of the absence in the New World of the necessary intermediate host.

Distribution and frequency. Loa loa is indigenous only in tropical West Africa where it is a frequent parasite in man. In certain sections

75 per cent of the native population have been found infected with this parasite. It occurs not infrequently in other countries among Europeans and Americans who have lived for some time on the West Coast of Africa.

Description. Loa loa is characterized by its nodular or wart-like cuticula. These bosses rise from 9 μ to 11 μ above the general surface of the body and are usually more numerous in the female. In the male they may be absent at the extremities. The male measures from 30 mm. to 34 mm. in length and about 0.35 mm. in breadth. The female varies considerably in length up to 70 mm. and is about 0.5 mm. in breadth. The average length of the female is probably about 50 mm. The microfilariæ are present in the circulating blood during the day only, appearing in the blood about eight o'clock in the morning and disappearing about nine o'clock in the evening. They, like the microfilariæ of *W. bancrofti,* are sheathed forms. They may be differentiated from the latter in dried and stained preparations by their stiff, ungraceful and angular attitude (Figure 206). The microfilariæ of *W. bancrofti* assume more sweeping and graceful curves. The nuclei forming the central column in the microfilariæ of *Loa loa* are larger and stain less deeply than those of *W. bancrofti.*

FIG. 206.—Showing characteristic altitudes of microfilariæ of A, *Wucheraria bancrofti* and B, *Loa loa.* (Redrawn from Manson in Brumpt)

Position in the host. The adult of *Loa loa* is primarily a subcutaneous tissue parasite. It is frequently observed just beneath the skin of the fingers, the eyelids and conjunctiva. It commonly makes excursions through the subdermal connective tissues and has been observed to travel at the rate of an inch in two minutes.

Life-cycle. Manson and Sambon early suspected that the flies of the family TABANIDÆ, the horse-flies, were agents in the transmission of *Loa loa,* and Leiper (1913) demonstrated that the microfilariæ may complete their development in *Chrysops dimidiata* and *C. silacea.* The developmental stages of *Loa loa* in these flies closely follow those of *W. bancrofti* within the mosquito. They complete their development within about ten days and are then found at the root of the proboscis. They break through the proboscis sheath and fall upon the skin of the person when the infected fly feeds. The Connals (1921) have found nearly 4 per cent of the wild flies of Calabar infected with *Loa loa.*

Pathogenesis. Aside from the itching and irritation caused by

these migrations the parasite apparently produces no serious damage to its host. The worms may be readily extracted through a small incision. It is generally believed that the localized edemas, known as Calabar swellings, are due to the presence of adult worms. These swellings appear suddenly and then gradually disappear. They may attain the size of a hen's egg and may occur on any part of the body, but frequently appear on the hand and forearm. They are said to be painless and never suppurate.

Other species of FILARIINÆ occurring in man are *Acanthocheilonema perstans* Manson, 1891; *Onchocerca volvulus* (Leuckart, 1893); *O. cæcutiens* Brumpt, 1919; *Dirofilaria magalhaesi* (R. Blanchard, 1895); and several species which are temporarily included under the genus *Filaria*.

(3) ACANTHOCHEILONEMA PERSTANS Manson, 1891. *Acanthocheilonema perstans* is widely distributed throughout Africa, especially along the western coast and the Congo. In certain districts 90 per cent of the population are infected. *A. perstans* is normally a parasite of man but may occur also in the chimpanzee. The adults of this species inhabit the mesentery and the perirenal and retroperitoneal tissues and the pericardium. The body is smooth and without markings. The microfilariæ are not sheathed and show no periodicity. The insect vector of *A. perstans* is not known, but it is supposed that certain of the TABANIDÆ or forest inhabiting mosquitoes are involved, in view of the fact that the infection is limited to inhabitants of dense swamps and forests. Towns and cultivated areas, as well as grassy plains, are said to be free from it. *A. perstans* is apparently non-pathogenic.

(4) ONCHOCERCA VOLVULUS (Leuckart, 1893). *Onchocerca volvulus* lives in subcutaneous tumors, especially in intercostal spaces, the axillæ and popliteal spaces. This species is also African in distribution and is especially frequent in the valley of the Congo and along the West Coast. In Sierra Leone, Blacklock (1926) has found 45 per cent of the persons examined infected with this parasite. It is especially prevalent in hilly countries covered with brush and grass and having abundance of streams and rivers. The microfilariæ are sheathless and are found in the skin, especially in the skin of the waist region. They are never found in the peripheral blood as in *W. bancrofti* and *L. loa*. The microfilariæ of *O. volvulus* present a great variation in size; the majority of forms in the skin measure from $250\,\mu$ to $300\,\mu$ in length by $5\,\mu$ to $9\,\mu$ in breadth. Blacklock (1926) has recently shown that the microfilariæ develop in the thorax of the black fly, *Simulium damnosum*. *O. cæcutiens* Brumpt, 1917, has been

reported from the higher altitudes of Guatemala and is apparently of fairly common occurrence in that country. It produces subcutaneous tumors especially frequent in the occipito-frontal and temporal regions and of the scalp and is also associated with a punctate keratitis commonly found in Guatemala. The life-cycle of *O. cæcutiens* is not known but it is probable that its larval development takes place in certain species of *Simulium*.

(5) Dirofilaria magalhæsi (R. Blanchard, 1895). *Dirofilaria magalhæsi* was discovered in the heart of a Brazilian child. The life-cycle of *D. magalhæsi* is not known but its transmission is probably by certain blood-sucking insects. A closely related species, *D. immitis* (Leidy, 1856) occurs in tangled masses in the right ventricle of the heart of dogs. The microfilariæ of *D. immitis* appear in the peripheral blood of the dog at night, and, when taken up by certain mosquitoes, particularly *Anopheles maculipennis* and *Ædes calopus,* they migrate to the malpighian tubules and there undergo larval development. In about twelve days they pass to the labium and are returned to another dog in a manner like *W. bancrofti* is returned to man.

(6) Filaria ozzardi Manson, 1897. This species was discovered by Ozzard in the blood of aboriginal Carib Indians of British Guiana. They closely resemble the microfilariæ of *Acanthocheilonema perstans* but have sharp tails, while those of the latter species are more or less rounded. They are non-periodic. The adult forms occur in the mesentery and visceral fat. The life-cycle is not known.

(7) Setaria equina (Abildgaard, 1789). *Setaria equina* appears to be a relatively frequent parasite of the peritoneal cavitv of horses and other equidæ, and has also been observed in cattle. It often wanders through the tissues and may be found in other parts of the body and sometimes invades the aqueous humor. It is then commonly termed "snake in the eye." In the eye it may cause inflammation with bulging and opacity of the cornea. It may be removed by operative measures. The males measure from 6 cm. to 8 cm. and the females from 9 cm. to 12 cm. in length. The posterior extremity of the male ends in a characteristic corkscrew spiral. The embryos are present in the blood vessels of infected animals. The life-cycle of this species is not known but it is probably transmitted from one host to another by some biting insect which becomes infected with the embryos in the blood stream.

Filariæ are very common in birds in the United States, particularly in crows and English sparrows. A single drop of their blood may contain thousands of microfilariæ. The microfilariæ may be kept alive for hours in fresh blood by rimming the cover glass with vaseline,

and permanent preparations may be made by methods outlined in a later section.

II. *Family Philometridæ* Baylis and Daubney (1926)

FILARIOIDEA with more or less elongated body, the anterior end of which is rounded and sometimes bears a cuticular shield. The mouth is simple, without lips, but is surrounded by six or eight papillæ. The anus may be absent in the adult. The male, when known, is much smaller than the female, with two equal, finely pointed spicules. A gubernaculum, or accessory piece, is present. The vulva is very inconspicuous or absent and the vagina is rudimentary or absent in gravid females. The uterine branches are directly opposed and form a continuous tube, with the ovaries situated at opposite ends of the body. The female is viviparous. These nematodes are parasitic in the body cavity, serous membranes or connective tissue of vertebrates. Example: *Dracunculus medinensis* (Linnaeus, 1758) in man.

1. DRACUNCULUS MEDINENSIS (Linnæus, 1758)

The female of this species is commonly known as the "guinea worm." This parasite has been known since the most remote period and it is very probable it is the "fiery serpent" which troubled the Israelites by the Red Sea, mentioned by Moses (*Numbers*, xxi). The adult female is unusually long and may attain a total length of over 100 cm., although the average is perhaps not over 90 cm. with a diameter from 1.5 mm. to 1.7 mm. A cuticular shield is present at the anterior end. The cuticula is smooth and presents a milky-white appearance. The alimentary tract below the esophagus is atrophied and is largely replaced by the long uterus which is filled with motile larvæ. The vulva is situated immediately behind the cephalic shield and during parturition the uterus is prolapsed through this opening. The anus is absent. The male is almost unknown. Two males 22 mm. in length were found by Daniels in a monkey which had been infected six months previously by Leiper. One was obtained from the psoas muscle, and the other from the connective tissue behind the esophagus.

Geographical distribution. Dracunculus medinensis is widely distributed and a common parasite of man in tropical Africa, Arabia and India and was imported into the West Indies and Brazil apparently during the slave days.

Position in the host. This parasite occurs most frequently in the subcutaneous connective tissues of man, especially of the arm, leg

and shoulders (Figure 207). Its presence is most frequently noted from June to August. Other reported hosts, besides man, are the dog, jackal, leopard, cattle, horse, baboon and the cobra. In some of these hosts other species of *Dracunculus* are perhaps involved.

FIG. 207.—*Dracunculus medinensis.* Showing the adult worm beneath the skin of the chest and abdomen. (Photograph by Macfie)

Life-cycle. The female worm when about to produce her young migrates to the parts of the skin which are likely to, or frequently do, come in contact with water, such as the arms and legs of laundresses, or the backs and shoulders of water carriers. The worm then pierces the lower layers of the skin with the head end of her body and a small vesicle soon appears and ulceration follows. A small hole may be seen at the base of the ulcer from which a portion of the anterior end of the worm may protrude. When the affected parts come in contact with water a milky fluid is discharged directly from the hole in the ulcer, or from the vulva if the worm is exposed to that extent. This fluid contains thousands of motile larvæ which may swim actively about in the water for two or three weeks (Figure 208). Fedtschenko, in 1879, discovered that these larvæ penetrate the carapace of *Cyclops,* a fresh water crustacean, and within the body cavity of that animal undergo metamorphosis. The larvæ are at first from 650 μ to 750 μ in length by 17 μ in breadth and are characteristically flattened forms with a long slender tail, well adapted for swimming.

Within the body cavity of *Cyclops* the larvæ acquire a cylindrical shape, and in from four to six weeks they become infective for man. Infection in man results from swallowing infected *Cyclops* in drinking water. The complete development of the worm in man is exceedingly slow and it is not until the worm is about a year old that it seeks the surface of the body to discharge the young.

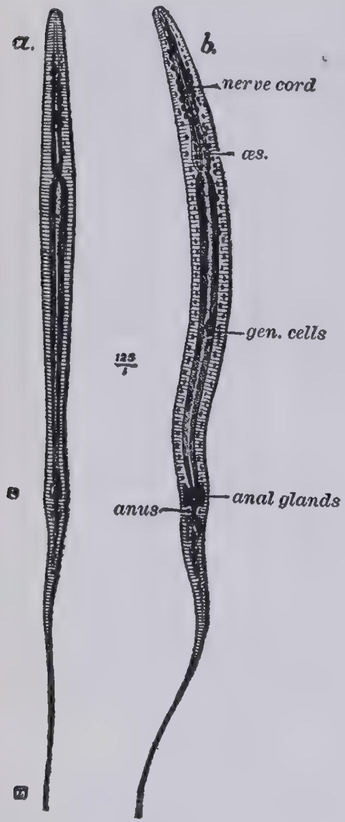


FIG. 208.—*Dracunculus medinensis.* Showing characteristics of larvæ. *a.*, side view; *b.*, front view. (From Manson-Bahr's *Manson's Tropical Diseases.* After Looss)

Pathogenesis. Aside from annoyance due to the migration of the worm beneath the skin, it is usually not dangerous if not interfered with. Should the worm break and the larvæ become discharged into the tissues, violent inflammation and fever, followed by abscess and sloughing, may develop and result in death from septicemia. Ulcers also may arise should the worm fail to reach the surface of the skin to bring forth her young. More often, however, her body becomes calcified and may be felt for years as a hard, twisted cord beneath the skin.

Treatment. For ages it has been the custom to extract the worm by gradually rolling it on a small stick. A few turns are given the stick each day until the worm is entirely drawn out. This method is, however, dangerous because the worm frequently breaks while still within the tissue and this may be followed by severe inflammation, abscess formation and conditions previously mentioned. It has been observed that the worm may be killed by injecting it with a 1 to 1000 solution of mercury bichloride and after twenty-four hours it may then be extracted without difficulty. If the worm is injected with a 10 per cent collargol solution it is made visible by the X-ray and may then be dissected out. Frequent douching the ulcer and the part occupied by the worm with cold water hastens complete

expulsion of the larvæ, after which the worm may emerge spontaneously or may be extracted without resistance.

Prevention. Knowing the life-cycle of this parasite, its prevention in man is not a difficult matter. Water supplies should be protected from pollution by guinea-worm patients. The use of only filtered water or boiled water is most effective against infection.

III. *Family Spiruridæ* Örley, 1885

FILARIOIDEA with the mouth surrounded by two lips. A buccal capsule is usually present. The esophagus consists of a short anterior muscular portion and a long and thicker posterior glandular portion. The male is equipped with two usually unequal and dissimilar spicules. The position of the vulva is variable but is never very close to the anterior end. The eggs are thick-shelled and contain an embryo when deposited. The adults are parasites of the esophagus, stomach and intestines of vertebrates while the larvæ, as far as is known, are parasites of arthropods. According to Baylis and Daubney (1926) this family contains five subfamilies: (1) SPIRURINÆ Railliet, 1915; (2) ARDUENNINÆ Railliet and Henry, 1911; (3) ACUARIINÆ Railliet, Henry and Sisoff, 1912; (4) PHYSALOPTERINÆ Stossich, 1898; and (5) THELAZIINÆ Baylis and Daubney, 1926. They are, for the most part, parasites of birds, reptiles and lower mammals. The ARDUENNINÆ and THELAZIINÆ contain a few species which are rare or accidental parasites of man.

1. SUBFAMILY SPIRURINÆ Railliet, 1915

SPIRURIDÆ with lips followed by a cuticular collar which is prominent dorsally and ventrally and may form dorsal and ventral shields overlapping the lips. The buccal capsule is without spiral or annular thickenings. The male is typically with four pairs of preanal papillæ; and a gubernaculum, or accessory piece is usually present. Examples: *Protospirura gracilis* Cram, 1924, in cats and *Habronema megastoma* (Rudolphi, 1819) in horses.

(1) HABRONEMA MEGASTOMA (Rudolphi, 1819). *Description. Habronema megastoma* is a small, whitish nematode which occurs in the stomach of the horse. It appears to be of wide distribution and, in this country, is especially prevalent in the southern United States where conditions favor its development. The female measures from 10 mm. to 13 mm. in length and the male from 7 mm. to 10 mm.

These worms live in nodules or tumors in the stomach and parts of their bodies may be seen projecting from small apertures at the summit of the tumor. Many of the worms may also be found free in the contents of the stomach. The worm-swellings are particularly common in July and may seriously interfere with the functioning of the stomach if situated near the pylorus.

The larvæ of *Habronema* are associated with skin lesions generally known as "summer sores" which are found along the ventral and lower portions of the body. They occasionally occur in the eyes.

Life-cycle. The embryos of *H. megastoma* pass out in the manure and become ingested by maggots of the house-fly (*Musca domestica*) as they feed in the manure. The infective stage is reached about the time the fly emerges from the pupal stage and is transferred to the final host when the infected fly comes in contact with the horse's lips or when the fly is swallowed by the horse, the latter opportunity arising when the benumbed flies fall into the feed boxes, mangers and drinking troughs while the temperatures are low in the early morning. The larvæ thus ingested escape from the flies in the stomach of the horse and there continue their normal development. It is generally believed that the summer sores arise as the result of the horse lying down on floors or soil covered with manure, thereby bringing abraded areas in contact with young larvæ in the manure. Infective larval worms from the fly when transferred to a wound cause an increase in the severity of the sore.

Habronema muscæ (Carter, 1861) and *H. microstoma* (Schneider, 1866) also occur in horses of this country. The larval development of *H. muscæ* likewise takes place in the house-fly. This fly can also serve as the intermediate host for *H. microstoma* but the development of this latter species usually takes place in the stable-fly, *Stomoxys irritans.* According to Roubaud and Descazeaux (1922) the larvæ of *H. megastoma* are exclusively parasitic in the malpighian tubes of the house-fly, whereas the larvæ of *H. muscæ* and *H. microstoma* are parasitic in the cells of the adipose tissue of their intermediate hosts.

2. SUBFAMILY ARDUENNINÆ Railliet and Henry, 1911

SPIRURIDÆ with trilobed but not prominent lips, and without dorsal and ventral cuticular shields. The buccal capsule, or pharynx, is typically with annular or spiral thickenings in its walls. Asymmetry is frequently present in the cervical and caudal alæ, and in the papillæ and other structures of the male. There are four pairs of preanal and

one or two pairs of large postanal papillæ present. Gubernaculum present. Examples: *Arduenna strongylina* (Rudolphi, 1819), in the stomach of pigs, and *Gongylonema scutatum* (Leuckart, 1873) in the horse, ox, goat and sheep.

(1) ARDUENNA STRONGYLINA (Rudolphi, 1819). This species is found in small tumors in the submucosa of the stomach and small intestine of pigs. It appears to be widely distributed throughout the United States. It is a slender, whitish worm, with the body often curved in a semicircle. The male measures from 10 mm. to 13 mm. in length and the female from 12 mm. to 20 mm. It is frequently found with *Physocephalus sexulatus* (Molin, 1860), a very closely related species. *P. sexulatus* appears to have as wide a distribution in the United States as *A. strongylina* but usually occurs less abundantly. It apparently has the same habits of injuring the mucosa as *A. strongylina*. *P. sexulatus* is differentiated from *A. strongylina* by the swelling of the cuticula at the anterior end and has three lateral alæ on each side. The tail of the male has narrow symmetrical alæ while in *A. strongylina* the alæ on the tail of the male are assymmetrical. These parasites are known to be the cause of a serious gastritis in pigs.

(2) SPIROCERCA SANGUINOLENTA (Rudolphi, 1819). *Spirocerca sanguinolenta* occurs in tumor-like formations of the esophagus and stomach of the dog. The tumors lie beneath the mucosa which remains unaltered with the exception of the opening at the tumor's summit. The tumors may vary in size from that of a hazelnut to that of a pigeon's egg and contain a purulent fluid and one to seven worms. The female worms are from 6 cm. to 8 cm. and the males from 3 cm. to 5 cm. in length and are easily distinguished by the blood-red color. Apparently it produces no serious disturbances. The eggs are passed with the dog's feces. When these are taken up by the cockroach, *Blatta orientalis,* an infective larva develops in the body cavity of this host. The infection in the dog results from having ingested infected cockroaches.

(3) GONGYLONEMA SCUTATUM (Leuckart, 1873). *Gongylonema scutatum* is a common parasite of sheep, cattle and goats in the United States and inhabits the mucosa of the esophagus. It is usually found in the thoracic portion where it is lodged immediately beneath the epithelium. The body is long and white, or yellowish-white in color. The anterior extremity of the body is studded with irregular longitudinal rows of cuticular bosses. The tail of the male is rolled up and has two asymmetrical alæ and two very unequal spicules. The vulva of the female is located immediately above the anus. The ova have a thick shell and contain an embryo at the time of deposition.

Life-cycle. The eggs of *G. scutatum* are passed with the host's feces, and, when ingested by various species of dung beetles, hatch in the intestinal tract. The newly hatched larvæ penetrate the gut wall

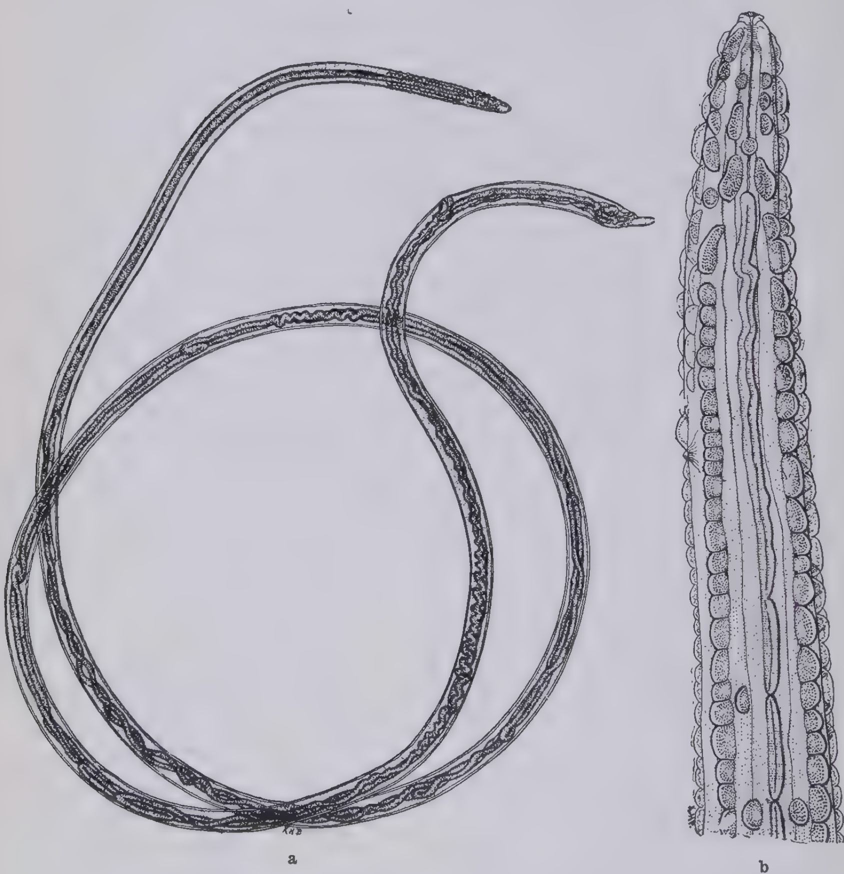


FIG. 209.—*Gongylonema pulchrum* from human host. a, adult worm (x 15). b, anterior end of same specimen (x 140). (After Ward)

and pass into the body cavity of the insect where the infective stage for the ruminant host develops within about one month. Sheep and cattle accidentally ingest insects along with grass and thus become infected. *Gongylonema* larvæ have been found by Ransom and Hall (1915) in various species of dung beetles collected from sheep manure, including *Aphodius femoralis, A. granarius, A. fimentarius,*

A. coloradensis, A. vittatus, Onthophagus hecate and *O. pennsylvanicus.*

Gongylonema pulchrum (Molin, 1857) (Figure 209) is a common parasite in pigs and the wild boar of Europe and has been found beneath the epithelium of the lip mucosa of a girl sixteen years of age in the United States (Ward, 1916). *G. ransomi* Chapin, 1922, has been described from pigs of the United States. According to Baylis (1925) it is probable that this species and *G. scutatum* are identical with *G. pulchrum.*

Gongylonema ingluvicola Ransom, 1904, has been reported in the mucous lining of the crop and occasionally in the undilated portion of the esophagus from chickens bought in the markets at Washington, D. C.

Gongylonema neoplasticum (Fibiger and Ditlevsen, 1914) occurs in the anterior portion of the digestive tract of rats, including the mouth, tongue, esophagus and fundus of the stomach and is a frequent cause of gastric carcinoma in this host. The embryonic development takes place in the cockroach, *Blatta orientalis.* Within twenty days after the ingestion of the eggs by this insect the fully developed larvæ may be found coiled up in the muscles of the prothorax and limbs. *Blatella germanica* and *Tenebrio molitor* may also serve as intermediate hosts for *G. nepolasticum.*

3. SUBFAMILY ACUARIINÆ Railliet, Henry and Sisoff, 1912

SPIRURIDÆ with quite distinct, but very small conical lips. The anterior tip is provided with "cordons," "epaulettes" or other homologous structures. The buccal capsule is thin-walled and without thickenings. There are typically four pairs of pedunculated preanal papillæ in the male. The spicules are unequal and usually quite dissimilar. There is no accessory piece. The eggs are ellipsoidal, with a thick shell and embryonated at time of oviposition. The ACUARIINÆ are parasites of the digestive tract of birds. Their life histories are, for the most part, unknown, but probably involve intermediate stages in arthropods or other small invertebrates which probably eat the eggs passed with the feces of the host. When such infected intermediate hosts are eaten by birds the larval worms grow to maturity. Examples: *Cheilospirura hamu-*

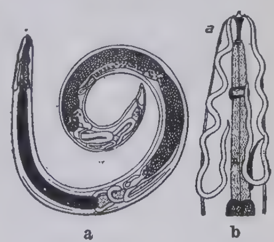


FIG. 210.—*Dispharynx spiralis.* a, female. (After Piana in Cram) b, head end. (From Cram. After Seurat)

losa Diesing, 1861, in fleshy growths on the surface and in the wall of the gizzard of chickens, turkeys and pheasants; *Dispharynx spiralis* Skrjabin, 1916 (Figure 210), often in papillomatous growths in the proventriculus and in the esophagus of chickens, ducks, pigeons, turkeys and pheasants. Larval development of this species takes place in the sow-bug, *Porcellio lævis.*

4. SUBFAMILY PHYSALOPTERINÆ Stossich, 1898

SPIRURIDÆ with two large and entire lips with forwardly-projecting teeth on their inner surface and frequently followed by a cuticular collar which is entire and does not form dorsal and ventral shields. There is no buccal capsule. The males have large, bare caudal alæ, joined anteriorly across the ventral surface and the caudal papillæ are pedunculated. The vulva of the female is anterior to the middle of the body. Their life histories are, for the most part, unknown, but probably involve intermediate stages in insects or other hosts. Parasites of the digestive tract, generally the stomach of reptiles, birds and mammals. Examples: *Physaloptera truncata,* Schneider, 1866, inhabits the proventriculus of chickens and pheasants. *P. constricta* (Leidy, 1856) occurs in water-snakes. Most recognized species are European, African or South American in distribution. The North American species are not adequately known.

Two species of *Physaloptera* have been found in man, (1) *P. caucasica* von Linstow, 1903, by Menetriès in Caucasia and (2) *P. mordens* Leiper, 1908, by Turner in the Transvaal, Africa. The latter species has also been found by Leiper in man of the Uganda Protectorate. It is apparently a normal parasite of monkeys and its presence in man is probably accidental.

5. SUBFAMILY THELAZIINÆ Baylis and Daubney, 1926

SPIRURIDÆ with inconspicuous lips and dorsal and ventral cuticular shields absent. Buccal capsule short and not well developed and without annular or spiral thickenings in its wall. The male with or without caudal alæ but typically with numerous preanal papillæ. Spicules usually very unequal. The tail of the female generally ends bluntly. The life histories are not adequately known but they probably all involve intermediate stages in other hosts. Examples: *Oxyspirura mansoni* (Cobbold, 1879) is found under the nictitating membrane and occasionally in the nasal cavities and sinuses of

chickens, turkeys and peacocks: *Cystidicola stigmatura* (Leidy, 1886) Ward and Magath, 1916, in the air bladder of salmoid fishes and, *Thelazia callipæda* Railliet and Henry, 1910, in the eye of the dog. *T. callipæda* has also been reported from the eye of a Chinese by Stuckley in 1917.

A number of forms whose relationships are uncertain have been appended to THELAZIINÆ by Baylis and Daubney. Among these is *Spinitectus gracilis* Ward and Magath, 1916, a common parasite in the intestine of fishes of the United States including the black crappie, sheepshead and white bass. This parasite may be recognized by the presence of a series of backwardly directed spines on the cuticula which diminish in size and number posteriorly.

IV. *Family Camallanidæ* Railliet and Henry, 1915

FILARIOIDEA without lips, and the mouth a dorsoventral slit followed by a large buccal capsule whose wall is either separated into two lateral scallop-shell-like valves or is continuous. The vulva is prominent and is situated in the middle portion of the body with the vagina directed posteriorly. The uterine branches are opposed with the posterior branch ending blindly without an ovary. Parasites of the alimentary tract of reptiles, amphibians and fishes. Examples: *Camallanus ancylodirus* Ward and Magath, 1916, in North American carp; *C. oxycephalus* Ward and Magath, 1916, in North American white bass and black crappie and *C. trispinosus* (Leidy, 1851), in tortoises.

The life-cycle of this group may be illustrated by that of *Camallanus lacustris* Zoega, 1776, as worked out by Leuckart. *C. lacustris* in the adult stage is parasitic in the intestines of several species of fish. The female is viviparous. The larvæ pass out with the feces and swim about in water where they may sooner or later become ingested by the fresh-water crustacean, *Cyclops*. They bore through the gut wall of the cyclops into the body cavity and there undergo metamorphosis. No further development takes place unless the infected cyclops is in turn eaten by a suitable fish host. When this occurs the larvæ are set free from the body of the cyclops by digestion and within ten to fourteen days the worms are fully matured and pair. In some species of *Camallanus* a second intermediate host is required.

Species of *Camallanus* are usually not difficult to obtain and make excellent material for morphological and life history studies.

V. *Family Cucullanidæ* Barreto, 1916

FILARIOIDEA with two large lips each bearing three papillæ, and surrounding the mouth, a dorsoventral slit. The esophagus is in two portions but is without a distinct glandular portion and is usually dilated anteriorly to form a large muscular "false buccal cavity." The spicules are equal and an accessory piece is usually present. A preanal, sucker-like organ is typically present in the male. The vulva is situated in the middle region of the body, or posteriorly. The vagina runs forward from the vulva. The CUCULLANIDÆ are, for the most part, parasites in the alimentary tract of fishes and turtles. *Cucullanus clitellarius* Ward and Magath, 1916, in the lake sturgeon, *Acipenser rubicundus,* and *Dacnitoides cotylophora* Ward and Magath, 1916, in the intestine of the yellow perch, *Perca flavescens,* and wall-eyed pike, *Stizostedion vitreum,* are representative species in North America.

VI. *Family Gnathostomidæ* Railliet, 1895

FILARIOIDEA with large trilobed lips having the cuticula of their inner surfaces thickened and usually raised into longitudinal toothlike ridges which meet or interlock. Male with caudal alæ supported by broad pedunculated papillæ. The vulva is situated in the posterior half of the body. The vagina of the female runs forward from the vulva and there are from two to four uterine branches. The eggs have thin colorless shells and are ornamented with fine granulations. Parasites of the stomach and intestine of fishes, reptiles and mammals. North American representatives of the family are *Gnathostoma horridum* (Leidy, 1856) from the stomach of alligators and *G. sociale* (Leidy, 1858) from the stomach of a mink. Yorke and Maplestone (1926) regard *G. sociale* a synonym of *G. spinigerum* Owen, 1836 (Figure 211), which occurs in cats of the Far East and has been occasionally found in man causing abscesses, tumors or a "creeping disease." *G. hispidium* Fedeschenko, 1872, a normal parasite in the intestine of cattle and hogs has been encountered in cutaneous lesions in man in China and Japan. All specimens of *Gnathostoma* obtained from man have been immature and it is therefore

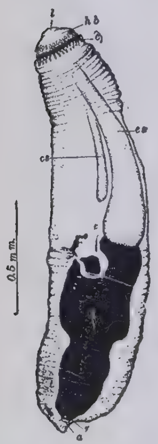


FIG. 211.—*Gnathostoma spinigerum. a,* anus; *c,* cuticular collar; *cs,* cervical sac; *es,* esophagus; *hb,* head bulb; *i,* intestine; *l,* lip; *r,* rectum. (After Faust)

evident, as pointed out by Morishita and Faust (1925) that these worms cannot settle down to develop to maturity in any organ of an unsuitable host like man, but wander in the host's body, especially in the surface and there cause cutaneous lesions.

CHAPTER XXIX

THE ORDER DIOCTOPHYMOIDEA

The order DIOCTOPHYMOIDEA consists of medium to large nematodes with the body sometimes spiny. Each of the four muscular fields are divided longitudinally into two by the insertion of well developed suspensory muscles of the alimentary canal. The mouth is hexagonal and is surrounded by one, two or three circles each of six papillæ. The esophagus is relatively long, simple or club-shaped. The tail of the male is furnished with a buccal cup, a closed bell-shaped, copulatory organ which is not supported by rays. A single long spicule is present. The anus of the female is terminal. The female genital system consists of but a single tube. The eggs are barrel-shaped with modified poles and with a thick pitted, albuminous coating. The adults are parasites of the digestive tract, kidneys and body cavity of mammals and birds and larval development occurs in an intermediate host.

I. *Family Dioctophymidæ* Railliet, 1916

1. DIOCTOPHYME RENALE (Goeze, 1782)

Dioctophyme renale (Figure 212) is one of the largest of the nematodes. The male measures from 14 cm. to 40 cm. in length by 4 mm. to 6 mm. in diameter. The female may attain a length of 1 m. and a diameter of from 5 mm. to 12 mm. The body is of a blood-red color. This species is most frequently found in the pelvis of the kidney, more rarely in the abdominal cavity, of the dog, and has been also reported from the seal, otter, wolf, horse, marten and polecat. According to Brumpt (1927) there are nine authentic cases of infection with this parasite in man.

D. renale grows to an enormous size within the kidney and produces a purulent material within which the worm lies coiled up (Figure 213). Only one kidney is infected, and usually with but a single worm. The infected kidney eventually becomes a mere thick-walled cyst while the uninfected kidney is usually found to have

undergone a compensatory hypertrophy. The diagnosis is made by finding characteristic ova in the urine.

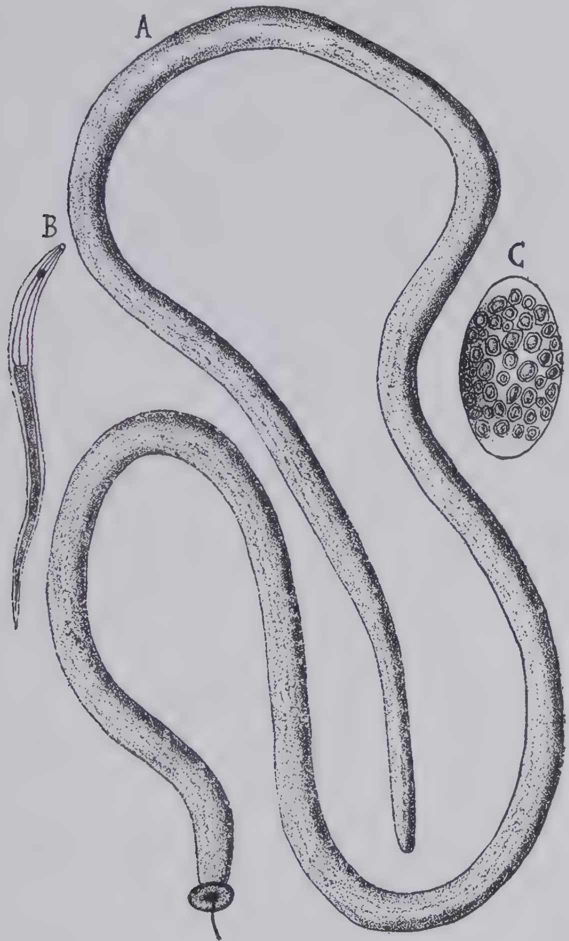


FIG. 212.—*Dioctophyme renale.* A, male, natural size; B, larva; C, egg (x 370). (From Neveu-Lemaire's *Parasitologie des Animaux Domestiques,* J. Lamarre, Paris)

Life-cycle. The embryonal development takes place in water or moist soils. The embryos are highly resistant and may remain alive for a year or more. The source of the infection in dogs or other hosts is not definitely known. Direct infection experiments with embryo-

nated ova have been unsuccessful and it has been thought that fish might serve as an intermediate host. This hypothesis is supported

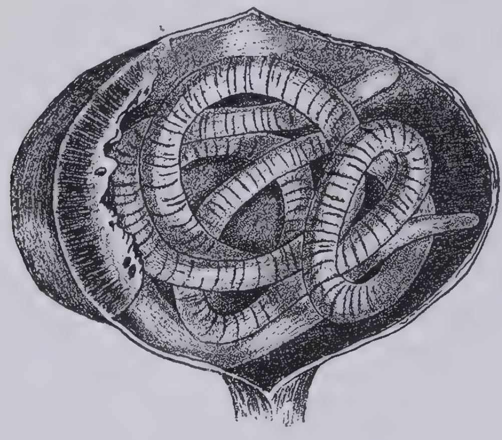


FIG. 213.—*Dioctophyme renale.* Female in the kidney of a dog, 2/3 natural size. (From Neveu-Lemaire's *Parasitologie des Animaux Domestiques,* J. Lamarre, Paris. After Railliet)

by the recent finding by Ciurea (1920) of a female specimen of *D. renale* intangled in the intestine of a dog which had been fed fish, *Idus idus,* from the Danube River. It is difficult, however, to explain this infection in horses from this source.

CHAPTER XXX

THE ORDER TRICHINELLOIDEA

The members of this order are characterized by a body more or less clearly divided into an esophageal portion and a posterior portion which contains the other organs. The esophagus is a cuticular tube embedded in a single chain of cells. The anus is terminal or subterminal in both sexes. The male is provided with a single spicule, enclosed in a sheath or without a spicule. The vulva of the female is located near the termination of the esophagus and the female reproductive system consists of only a single tube. This order contains but one family, the TRICHINELLIDÆ Stiles and Crane, 1910. It is made up of three subfamilies, (1) TRICHINELLINÆ Ransom, 1911; (2) TRICHURINÆ Ransom, 1911; and (3) TRICHOSOMOIDINÆ Hall, 1916.

I. *Subfamily Trichinellinæ* Ransom, 1911

TRICHINELLIDÆ, males of which are without spicule or spicule-sheath. The eggs are without a true shell but are surrounded by a delicate membrane. The adults in the intestine give rise to larvæ which become encysted in the musculature of the same host. Females viviparous. Example: *Trichinella spiralis* (Owen, 1835).

1. TRICHINELLA SPIRALIS (Owen, 1835)

Historical. Trichinella spiralis, commonly termed the "trichina worm," was first known by its larval stage encysted in the muscular system of man. It was observed in London by Peacock as early as 1828 and was described in 1835 by Owen as *Trichina spiralis* from an Italian in London who had died of tuberculosis. It was soon found in man throughout Europe and North America and was discovered in the pig by Leidy in Philadelphia. Leuckart and others commenced feeding experiments and it was discovered that the larvæ become adults within a few days in the intestine, and that the female is viviparous. The parasite was considered harmless to man until 1860, when Zenker found the adult worms in the intestine of a young

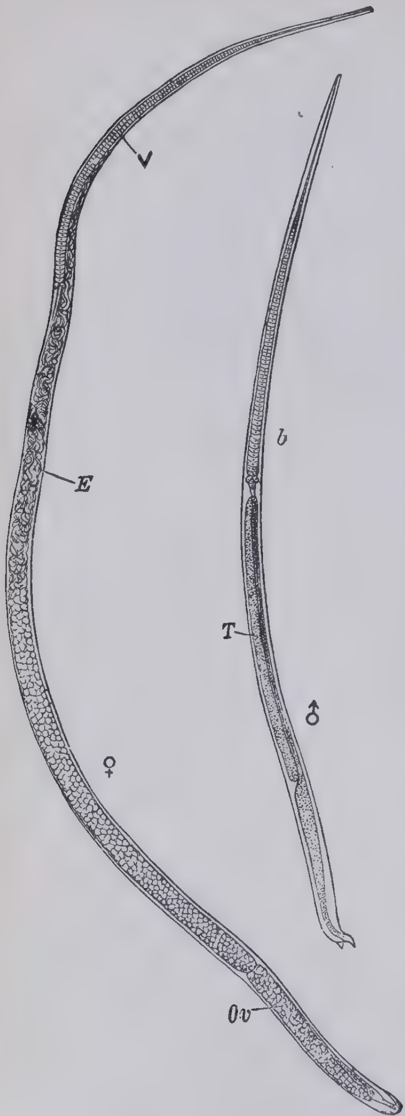


Fig. 214.—*Trichinella spiralis.* Mature female. V, vulva; E, embryos; Ov, ovary. Mature male, T, testis. Magnified. (After Claus)

girl who had died in a Dresden hospital, supposedly of typhoid fever. At autopsy the intestine did not show characteristic typhoid lesions but numerous adult trichinæ were found. The history of the case revealed that she had taken ill shortly after eating pork and, at the same time, several others who had also eaten of the same pork were sick, and pieces of the meat were full of the *Trichinella* larvæ. Numerous other similar cases were observed, many of which occurred in epidemic form. From 1881 to 1898 serious epidemics occurred, particularly in Germany, and during this time American pork was excluded from the German markets because of the alleged frequency with which it was found infected with *Trichinella.* A systematic inspection of pork was then started which led to our present day system of Federal meat inspection. An examination for trichinous pork, however, is not now included in this inspection for reasons which will be discussed later.

Description. The adult males measure about 1.6 mm. in length by 0.04 mm. in breadth and are characterized by the body tapering anteriorly and by the two lateral hemispherical lobes at the posterior extremity which serve during copulation. The adult female (Figure 214) measures from 3 mm. to 4 mm. in length by 0.06 mm. in breadth. The vulva is situated in the anterior

fifth of the body. Fertilized ova in various stages of development may be seen in the ovary which occupies the posterior extremity, and, as the female is viviparous, larvæ may be seen in the upper third of the uterus. Newly escaped larvæ, about 0.1 mm. in length, may be seen in fresh preparations.

Position in the host. The adult worms inhabit the small intestine of various mammals while the larvæ are found encysted in the voluntary muscles of the same animal which harbors the adult. Most animals may be experimentally infected with trichinæ but those of omnivorous or carnivorous habits are most frequently parasitized under natural conditions. From the public health standpoint the only animals in this country which are sources of infection and propagators of the disease are hogs and rats. Man becomes infected from eating trichinous pork, and hogs become infected from eating the carcasses of other infected hogs, offal from slaughter houses and infected rats. Rats, in turn, acquire the parasite by eating the flesh of trichinous hogs or by eating other rats which happen to be infected.

Geographical distribution and incidence. Trichinella spiralis is world-wide in distribution and, as it is transmitted from host to host solely as the result of one host eating the flesh of another, its frequency in man depends upon the frequency of the infection in hogs used for food, and upon the extent to which insufficiently cooked, raw or imperfectly cooked pork is eaten. It is by no means an unusual infection in man in the United States, although the actual incidence is not known because light cases fail to come under the physician's care or are wrongly diagnosed. It appears to be particularly frequent in New York, Pennsylvania and Massachusetts and the mortality of the infected cases is estimated between 6 per cent and 16 per cent. (Ransom, 1915). The disease rarely occurs among Americans, English and French who habitually thoroughly cook their pork. Fatal epidemics have occurred particularly among Germans, Austrians and Italians who are fond of raw pork, especially in sausage form and raw spiced hams. In America the infections are most frequent among people of foreign birth who still cling to the food habits of their native countries. The infection in American hogs is quite accurately estimated to be between 1 per cent and 2 per cent while in rats the infection rate varies considerably. In certain parts of the United States it has been as high as 77 per cent.

Life-cycle. The life-cycle of *Trichinella spiralis* may be easily followed by feeding a small piece of trichinous muscle to a series of

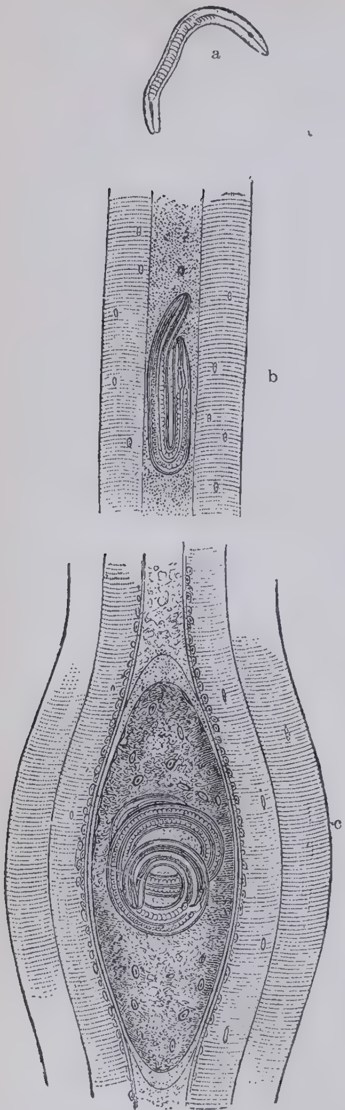


FIG. 215.—Larval stages of *Trichinella spiralis*. a, newly born larva; b, larva in muscles; c, encysted larva in muscles. Magnified. (After Claus)

white rats or guinea pigs followed by examinations of different individuals at stated intervals. The encysted larvæ are already in an advanced stage of development and when ingested with raw or insufficiently cooked meat they escape from their cysts in the stomach and small intestine where they may reach sexual maturity within as short a period as forty-eight hours. Mating then occurs. After fertilization the female worms burrow more or less deeply into the mucosa of the intestine so that they commonly reach the lymph spaces of the villi. The female is viviparous and deposits the larvæ in successive batches directly into the lymph spaces, or in different parts of the mucous membrane from which they gain entrance by their own activity into the lymph spaces. They are eventually carried to the blood stream, and then by the blood stream to all parts of the body. They are, according to Staübli (1909), most numerous in the circulating blood between the eighth and twenty-fifth day after infection and may be demonstrated at this period in the blood by means of centrifugalization. Those larvæ which are carried to voluntary muscles leave the capillaries and quickly penetrate into the primary muscle bundles. It is usually those muscles with the richest blood supply which are most heavily parasitized, such as the diaphragm, intercostal, laryngeal, tongue and eye muscles and the greatest invasion takes place about the tenth day after infection. The larva when it enters the muscle fiber measures about 0.1 mm. in length and 0.006 mm. in

breadth. It comes to lie along the long axis of the fiber and quickly grows in length reaching a total length of about 1 mm. within ten to fourteen days and then assumes the characteristic spiral form of the encysted parasite. The invaded muscle fiber rapidly undergoes more or less degeneration. A lemon-shaped cyst wall is formed around the larva which has an average size of about 0.5 mm. in length by 0.25 mm. in breadth and usually contains one, sometimes two or three larvæ, nuclei and a cytoplasm which represents the waste products of the larvæ and the remains of the degenerated muscle fiber. Calcification of the capsules may occur as early as six months but usually cyst walls are not completely covered until after one or two years. The larvæ thus encapsulated may remain alive for many years, whereas the length of life of the adults in the intestine is usually limited to a very few weeks. The newly formed cysts are invisible to the unaided eye, but, after calcification has taken place, the cysts give a characteristic fine sanded or granular appearance to the cut surface of the infected muscle, especially in massive infections (Figure 215).

A considerable amount of development of the larvæ takes place within the cyst. The reproductive organs are formed, but are not matured, and the larvæ show sexual differentiation. It is for this reason that the larvæ become mature so quickly after ingestion by the host.

Course of the disease. The severity of trichinosis depends upon the number of infective parasites ingested. A few may cause no noticeable symptoms. Most cases, however, are characterized by the presence of more or less severe gastro-intestinal disturbances, muscular tenderness and continuous fever. In man the course of the disease can usually be divided into three stages each of which is closely related to the different stages of development of the parasites within the host.

The first stage may begin in a few hours to a week after the ingestion of the trichinous pork and usually symptoms are those of gastrointestinal irritation and consist of lack of appetite, nausea, abdominal pains and diarrhea. During this period the worms are developing in the intestine. The second stage includes the second week and is associated with the distribution of the larval forms throughout the body and their penetration into the muscle fibers. There are usually severe muscular pains, especially in the flexors and the muscles become swollen, tense and hard. There may also be pain and difficulty in chewing, swallowing and breathing and dyspnea may be intense. The temperature may reach 104° F. or 105° F. The third

stage usually begins some six weeks after infection and follows the encystment of the larvæ. The patient becomes emaciated and anemic, and pneumonia is a common complication. Recovery is usually a slow process and sometimes is not established for several months. Death, due to exhaustion or pneumonia, occurs most frequently during the fourth to sixth week.

Occasionally the larvæ involve the central nervous system and may give rise to neurologic symptoms (Van Colt and Lintz, 1914; Salan and Schwartz, 1928). In such instances larvæ may be demonstrated in the spinal fluid. These may be regarded as stray larvæ. They do not become encysted in nervous tissue and they soon perish. The lesions which they may have caused are marked by areas of sclerosis (Mallory, 1914).

It has been stated that the fever and other pronounced symptoms in trichinosis are due to toxins derived directly from the trichinæ. There is, however, no experimental evidence to support this view, and it has been observed that no pronounced symptoms are produced when adult worms are ground and injected directly in the veins of a mouse (Tyzzer and Smillie, 1927). Flury (1913) has shown that the chemical composition of the parasitized muscle rapidly undergoes great changes following the invasion of the fibers by the trichinæ larvæ and regards the substances thus produced to be the direct cause of fever, muscular pains and edema. There is no appreciable immunity conferred after one or more attacks of trichinosis, nor does serum from animals convalescent from trichinosis when injected into other animals produce an immunity to trichinosis in the latter (Schwartz, 1917).

Diagnosis. A pronounced leucocytosis is the rule in trichinosis and is an important diagnostic point in distinguishing it from typhoid fever. Eosinophilia is almost always present and begins at the time of migration of the larvæ. An eosinophilia of 30 per cent is common and has been found as high as 86 per cent (Ransom, 1915). A positive diagnosis is made by demonstrating the larvæ, by means of centrifugalization, in the circulating blood, or by finding the larvæ in a bit of excised muscle, usually taken from the calf of the leg. The disease is most easily recognized when occurring in several members of the same family or in epidemic form. Under such conditions the source of the infection can usually be traced to certain raw or insufficiently cooked pork, and very frequently to pork in raw sausage form which has been home-made or prepared in meat shops on a small scale. Very often the sausage responsible for the outbreak of trichinosis has been made from one or two hogs.

Treatment. The treatment of trichinosis is entirely symptomatic. No known drug is effective against the larvæ in the blood or in the muscle fibers. According to Ransom (1915), attempts to expel the adult worms from the intestines by anthelmintics and cathartics probably do more harm than good, except perhaps in the very earliest stages within a few hours or a day after the ingestion of the trichinous pork. Unfortunately, however, the diagnosis is not made until the larvæ are already in the circulating blood or in the muscles.

Prevention. Although trichinosis is relatively common in pigs, the chances of infection in man may be entirely avoided by eating pork only after it has been thoroughly cooked or thoroughly cured. For detailed account of the effects of pork-curing processes on trichinæ, the reader is referred to Ransom (1920). The microscopic inspection of pork is not a safeguard against trichinosis. In many instances trichinous pork has been examined microscopically as many as twenty or thirty times before the parasites were found. Stiles has shown that nearly one-third of the cases of trichinosis occurring in Germany between 1881 and 1898 were caused by hogs inspected and passed as free from trichinæ (Ransom, 1915). Because of the unreliability of microscopic inspection for trichinæ it is not included in the system of meat inspection in this country. Therefore the Government mark, "U. S. Inspected and Passed," on pork does not guarantee that the meat is trichinæ free and it should be thoroughly cooked or thoroughly cured before it is used for food. One of the most important of all measures against trichinosis in man is the education of the individual as to the danger of eating raw or insufficiently cooked pork.

To prevent trichinosis in hogs, the accomplishment of which would likewise eliminate the infection in man, no uncooked offal should be given them and a persistent warfare should be made against rats, especially those in slaughter houses, butcher shops and markets.

II. *Subfamily Trichurinæ* Ransom, 1911

TRICHINELLIDÆ. Males with one spicule, or exceptionally, with only a spicule-sheath. The eggs are lemon-shaped, with a thick shell and polar opercula and are unsegmented when deposited. The development, so far as known, is direct. Example: *Trichuris trichiura* (Linnæus, 1771) in man.

1. TRICHURIS TRICHIURA (Linnæus, 1771)

Trichuris trichiura is generally known as the whip-worm of man. It is most frequently found in the cecum and the appendix and more rarely in the large intestine of man. It has also been found in monkeys and LEMURIDÆ. The whip-worm is world-wide in distribution, but like many other helminths, it is most frequent in the tropical and subtropical countries.

Description. The whip-worm (Figure 216) is of a grayish or pinkish color. The anterior portion of the body is much attenuated, hence the derivation of its common name, "whip-worm." The anterior portion is longer than the posterior portion, or body proper. The males measure from 30 mm. to 45 mm. and the females from 30 mm. to 50 mm. in length. The eggs are characteristically of a barrel shape, brown in color and measure from 51 μ to 54 μ in length by 22 μ in breadth and are unsegmented at time of deposition.

FIG. 216.—*Trichuris trichiura.* A, females; B, males. The posterior portion of the male is usually coiled as is shown at the right. Photographs of mounted specimens. Natural size. (From Todd's *Clinical Diagnosis,* W. B. Saunders Company)

Life-cycle. The development of the embryo is very slow and may require from six months to a year before it is completely formed.

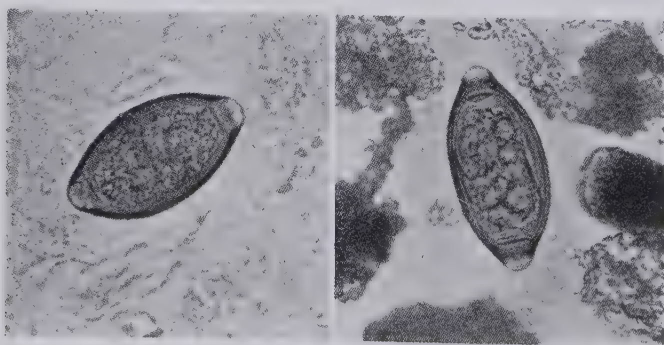


FIG. 217.—Eggs of *Trichuris trichiura* in feces (x 500). (From Todd's *Clinical Diagnosis,* W. B. Saunders Company)

The eggs are very resistant and, like those of *Ascaris,* may live for a long period in the open. The method of infection is direct and once the ripe egg is ingested by man or another suitable host the

embryo escapes from the egg-shell and, according to Hasegawa (1924), penetrates the villi of the intestine, especially the villi of the cecum, and there rests for two or three days near the glands of Lieberkühn. It then passes into the lumen of the cecum where development proceeds to maturity. Eggs may appear in the host's feces thirty-six days after infection.

Pathogenesis. The whip-worm is commonly found with its whip-like anterior portion imbedded superficially in the mucous membrane. This species has been associated with appendicitis but it is generally believed to be of no great importance in human pathology.

Other species belonging to this genus are *Trichuris vulpis* in dog and wolf; *T. suis* in pig; *T. ovis* (Figure 218) in sheep and cattle; *T. leporis* in rabbits.

Treatment. The whip-worms are difficult to remove by anthelmintics on account of their position in the host. The latex of a wild fig tree, *Ficus glabrata,* of Central America and Colombia is known to be effective against *Tri-*

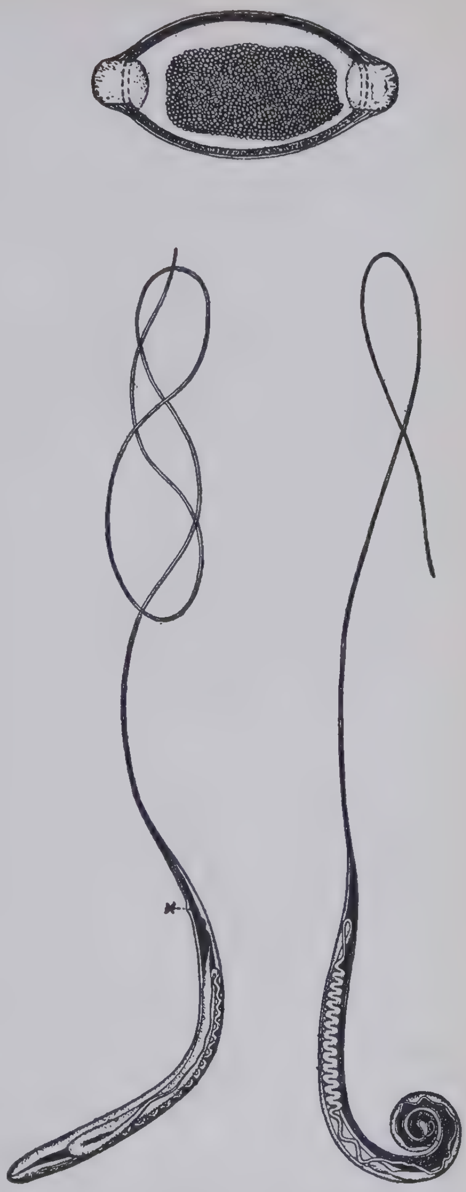


FIG. 218.—*Trichuris ovis.* Upper figure, egg (x 600); lower figure, right, male; left female; * vulva (x 55). (From Ransom. After Curtice)

churis when used in the fresh state. This drug may be taken in large doses 30 ml. or more, without any apparent discomfort to the patient.

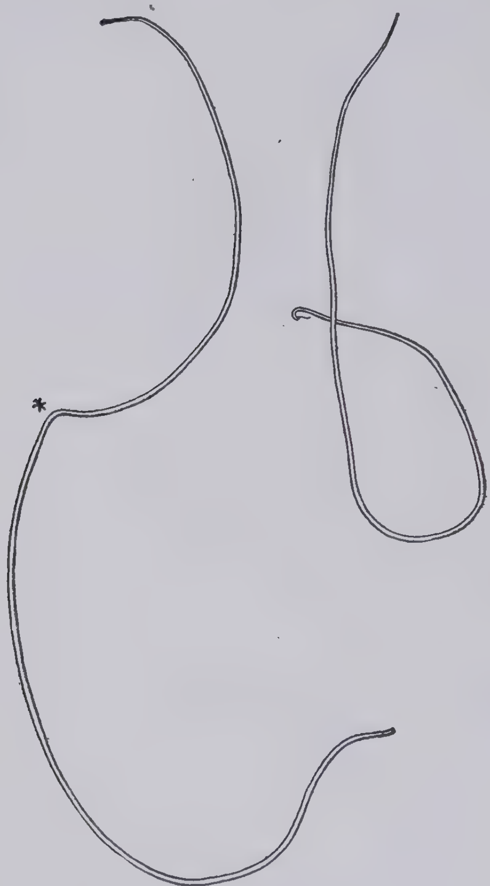


FIG. 219.—*Capillaria* [*Thominx*] *brevipes*. Right, male; left, female. * vulva (x 15). (After Ransom)

Prevention. Measures taken against *Ascaris* are equally effective against *Trichuris.*

The genus *Capillaria* Zeder, 1800, is frequent in birds and mammals, not including man. This genus is characterized by the esophageal portion being shorter than, or rarely equal in length to the posterior portion. Representative species are, *Capillaria brevipes* (Figure 219)

in the small intestine of sheep, and *C.* [*Thominx*] *annulata* in and beneath the thickened lining of the gizzard of pheasants.

2. HEPATICOLA HEPATICA (Bancroft, 1893)

Hepaticola hepatica is a frequent and sometimes fatal parasite of rats and other rodents. It occurs in the liver and may be recognized by the short esophageal portion and the slightly thicker posterior portion of the body. This species has been reported once from man, a British soldier in India who had died from septic pneumonia secondary to a liver abscess caused by the accumulation of these worms and their eggs.

FIG. 220.—*Trichosomoides crassicauda.* Mature female with male in uterus. (After Hall)

III. *Subfamily Trichosomoidinæ* Hall, 1916

TRICHINELLIDÆ, males without spicule or spicule-sheath and occurring in the vagina or uterus of the female. The eggs have thick shells with polar opercula and contain embryos when deposited. The development is direct. Example: *Trichosomoides crassicauda* (Bellingham, 1840), in the urinary bladder, pelvis of the kidneys and ureters of rats. According to Yokogawa (1920) the larvæ after hatching in the stomach and intestine of the rat pass to the lungs before they become established in the bladder, and are probably carried from the lungs to the bladder in the blood vessels. Calculosis, papillomata and malignant growths of the bladder are believed to have been caused by these worms and their eggs.

CHAPTER XXXI

APPENDIX TO NEMATHELMINTHES

I. *Gordiacea*

I. GENERAL DESCRIPTION

The GORDIACEA are long, thin worms generally known as "horse hair snakes." They are larger than the nematodes and are more uniformly cylindrical, with blunt rounded anterior ends, and with the caudal end swollen, lobed or curled in a loose spiral. They usually show some coloration. Their resemblance to the nematoda is, however, only superficial, and in finer details of structure they have little in common with them. There are no lateral lines and the body is opaque. The cloaca, or common outlet of the reproductive and alimentary systems, is present in both sexes and is situated near the posterior extremity of the body. The male never possesses spicules. The body cavity is lined by epithelium. The gonads are not continuous with their ducts. The ova are discharged into the body cavity and then pass into the ducts. In sexually mature worms the alimentary tract is atrophied.

The adults live free in water and are frequently found in the country in drinking troughs, ponds, streams and puddles of water formed by heavy rains. The larval forms are, however, parasitic and frequently occur in water insects, usually land insects which have aquatic stages.

2. LIFE-CYCLE

The female deposits long strings of eggs on aquatic vegetation and these develop into small larvæ, characterized by a proboscis armed with hooks. The newly-hatched larva swims about in the water for a time and enters into an aquatic insect, usually the larva of the mayfly. After a period the still immature worm passes into new hosts, namely, beetles, crickets and grasshoppers, where it continues development in the body cavity. The mode of transfer of the infection to these hosts is not clearly known, but in the case

where the first host is the larva of a mayfly, and the second a carnivorous beetle, it has been suggested that in a season of drought, when the pools become dry, the mayfly larvæ become the easy prey of beetles, and when feeding upon them the beetles take in the young hair snakes. Development continues within the body cavity of the new host until the worm is almost full grown, when it escapes into the water and becomes sexually mature. As the final host is usually a terrestrial insect it is necessary that this host become drowned in water in order that the adult worms can reach their natural environment. It is for this reason that the hair snakes are found most frequently in bodies of water following a rainstorm or flood.

A number of adult GORDIACEA have been reported as human parasites. It is possible that they were accidentally swallowed with drinking water, or what is quite as likely, they were reported to physicians as parasites by patients with hysteria. Among those species reported for man are *Gordius aquaticus; G. chilensis; Pengordius varius* and *Parachordodes alpestris.*

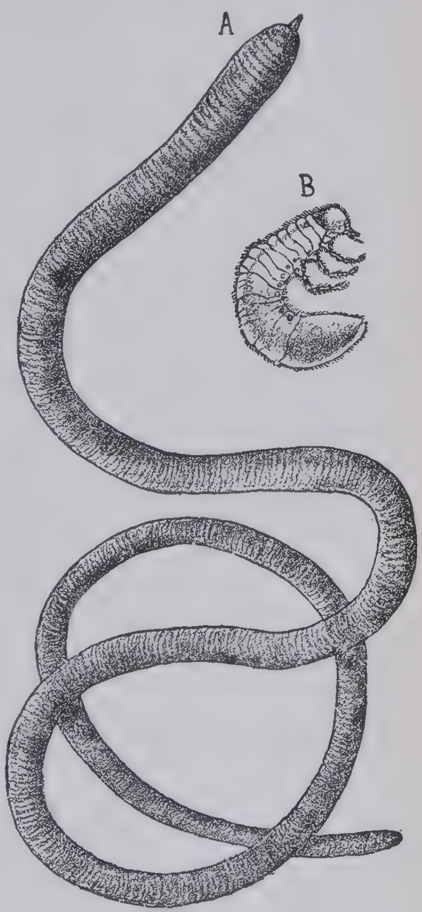


FIG. 221.—*Macracanthorhynchus hirudinaceus.* A, female, natural size; B. larva of Melolontha vulgaris, an intermediate host. (From Neveu-Lemaire's *Parasitologie des Animaux Domestiques,* J. Lamarre, Paris)

II. *Acanthocephala*

1. GENERAL DESCRIPTION

The ACANTHOCEPHALA include the "spineheaded worms." The adults occur only in the intestine of vertebrates and are commonly attached to the intestinal wall by means of a protrusible proboscis which is almost

invariably covered with hooks. The ACANTHOCEPHALA, like the GORDIACEA, bear only superficial resemblance to the nematoda. They characteristically present a roughened surface and have a more or less spindle-shaped form. At no stage in their life history is there any trace of an alimentary system. The reproductive system is very complex. In the female there is no persistent gonad. The egg masses are formed early and, after fertilization, these break up into individual spined embryos, each of which becomes surrounded by three embryonic membranes. They are usually oval in form. The ACANTHOCEPHALA are common parasites of fishes and birds but may also occur in other vertebrates, including man.

2. LIFE-CYCLE

The life-cycle of ACANTHOCEPHALA is poorly known but probably there is always an alternation of hosts during development. For example, the embryos of *Macracanthorhynchus hirudinaceus,* a common parasite of pigs, develop in terrestrial beetle larvæ, and those of *Moniliformis moniliformis,* which usually occurs in rats and other rodents, develop in the cockroach. In aquatic species it is inferred that the ripe embryos become ingested by a suitable host, probably a crustacean, in the body cavity of which it develops to the stage infective for the final host.

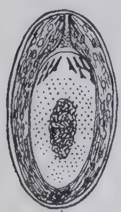


FIG. 222.—Egg of *Macracanthorhynchus hirudinaceus.* Magnified. (Partly after Leuckart)

Macracanthorhynchus hirudinaceus (Figure 221) has been reported from man and *Moniliformis moniliformis* appears to be a facultative parasite in man. Several species of the genera *Echinorhynchus* and *Neœchinorhynchus* occur in American fishes. The ACANTHOCEPHALA occur only exceptionally in human beings and are not of economic importance.

CHAPTER XXXII

METHODS OF DIAGNOSING HELMINTH INFECTIONS

The diagnoses of the majority of helminth infections are made by the finding of their ova or larvæ in the feces or discharges of the host. The eggs of the lung fluke, *Paragonimus westermani,* are usually searched for in the sputum from suspected cases, although, because of conscious or unconscious swallowing of the sputum, they may also appear in the feces. The diagnosis of filarial infections is generally made on larval stages, the microfilaria, and, since these larval stages are usually found in the blood stream, examinations of the blood are used in determining their presence or absence.

I. *Diagnosis Based on Clinical Symptoms*

Clinical symptoms accompanying many helminth infections are generally not to be relied upon for the absolute diagnosis of helminth infections. This is largely because light infections generally do not produce noticeable symptoms and because of the variable susceptibility of different individuals to worm infections, even when they may occur in fairly large numbers. Furthermore, clinical symptoms due to such infections may often be misleading and an entirely erroneous diagnosis may be made from them. They might suggest a number of morbid conditions which have no parasitological connection whatever, and again, clinical symptoms due to other causes may be, and have been ascribed to a non-existing helminth origin. Wherever it is possible, the diagnosis derived from clincal manifestations should be confirmed by a laboratory examination in which a search is made for direct evidence of the parasite itself.

II. *Methods of Fecal Examination*

The eggs of the parasitic worms may be recognized readily with the aid of the microscope. Every species has its characteristic

shape, size and color, its shell markings and its stage of development when appearing in fresh feces; and the appearance of larvæ, if present, is also of diagnostic value.

Several methods have been devised for identifying eggs and larvæ, as well as for determining the intensity of the infection within the host. Descriptions will be given here only of the methods which are now most generally used for these purposes.

1. THE DIRECT SMEAR

This is the simplest of all methods of fecal examination. A particle of feces not larger than the head of a match is placed on a 2 x 3 inch glass slide and mixed well in a drop or two of water or normal saline. The film, thus formed, is examined under the low power of a microscope without a cover-glass. A cover-glass may be used which will increase the visibility. Heavy infections can easily be detected from a single examination but in lighter cases this method is highly inaccurate. In examinations for hookworm this method is believed to be diagnostically accurate if the intensity is such that 500 or more eggs are present per gram of feces.

2. CENTRIFUGAL METHODS

A quantity of feces, from 4 to 5 grams, is thoroughly stirred and agitated in filtered or distilled water until an emulsion is formed. This emulsion is strained through gauze to remove the larger particles and then centrifuged. The relatively heavy ova are thus concentrated at the bottom of the centrifuge tube. The residue is then transferred to glass slides and examined as smears.

Lane has devised a modification of the centrifuge method in which a measured amount of feces is used. After centrifugation in water, the residue is thoroughly agitated in concentrated salt solution. The eggs, if present, are thus brought to the surface, and a cover-glass is placed upon the mouth of the tube between four special metal horns surrounding the centrifuge guard. The tubes are then again centrifuged and the glass cover slide examined as a "hanging drop" preparation under the low power of a microscope for eggs. This method has been found to be exceedingly accurate in diagnosing hookworm infections, but has the objection that special apparatus is required for its operation.

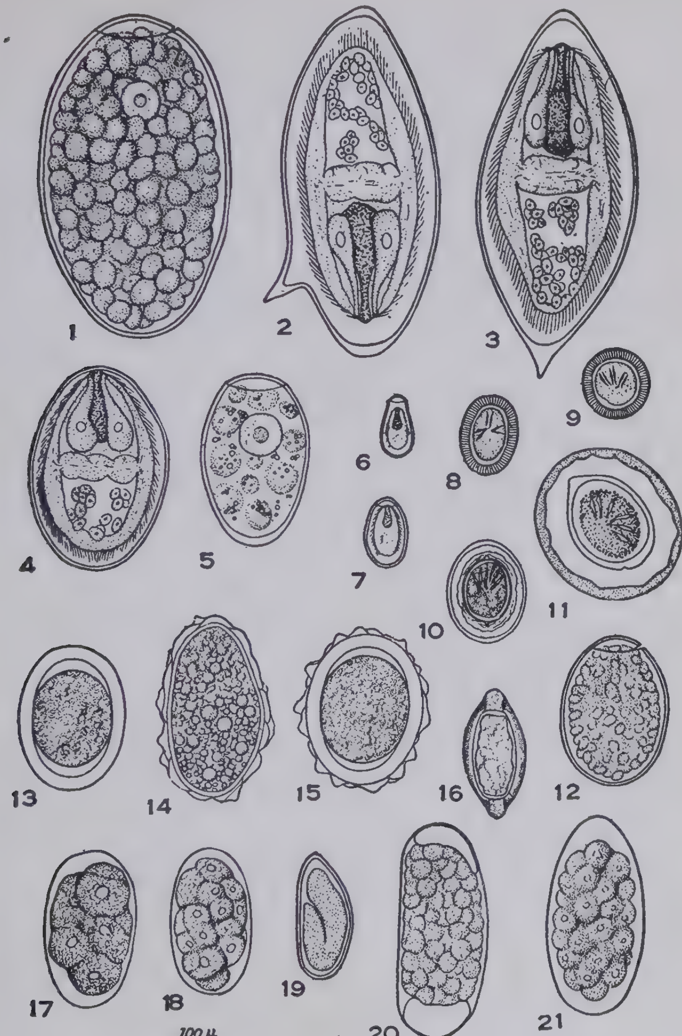


FIG. 223.—Eggs of the most important helminths of man. 1, *Fasciolopsis buski.* 2, *Schistosoma mansoni.* 3, *Schistosoma hæmatobium.* 4, *Schistosoma japonicum.* 5, *Paragonimus westermani.* 6, *Clonorchis sinensis.* 7, *Metagonimus yokogawai.* 8, *Tænia saginata.* 9, *Tænia solium.* 10, *Hymenolepis nana.* 11, *Hymenolepis diminuta.* 12, *Diphyllobothrium latum.* 12, *Ascaris lumbricoides* (egg without outer coating). 14, *Ascaris lumbricoides* (abnormal egg). 15, *Ascaris lumbricoides.* 16, *Trichuris trichiura.* 17 and 18, Hookworm eggs. 19, *Enterobius vermicularis.* 20, *Heterodera radicicola* (*Oxyuris incognita*). 21, *Trichostrongylus orientalis.* (From Hegner, Cort, and Root, *Outlines of Medical Zoölogy*)

3. LEVITATION METHODS

A number of methods for quick and efficient examinations have been devised in which the fecal sample is mixed with some solution heavier than the worm eggs. The eggs are thus concentrated at the surface of the mixture. While these methods are very accurate, even in very light infections, they will, as in Lane's technic, have the disadvantage that larvæ and operculate eggs burst in the salt solution and therefore do not float in the medium. These methods should not be employed to detect the presence of larvæ of *Strongyloides* or eggs of trematodes and those of the fish tapeworm of man, *Diphyllobothrium latum.* All of these so-called "levitation" methods were purposely devised for the rapid detection of hookworm ova.

Kofoid-Barber brine-loop-flotation method. A fairly large fecal sample is thoroughly mixed with concentrated salt solution in cylindrical containers of two or three ounce capacity. The coarse float is forced to the bottom with a thin disk of No. 0 steel wool. The preparation is then allowed to stand for one hour, giving time for the eggs to rise, after which the surface is looped off with wire loops, approximately 7 mm. in diameter, to glass slides. The examination is made with the low power of a microscope and the microscope focused on the upper drop of the slide. This method gives a very clean preparation for study and a good concentration of ova.

Willis' method. In this method a small amount of feces, about 1 to 2 grams, is thoroughly mixed with concentrated salt solution. The container is then filled to the brim with the salt solution and a clean glass slide of such size that it will more than cover the container used, is placed thereon and allowed to stand for several minutes. The slide is then carefully removed, inverted and examined under the low power of the microscope. Care must be taken in removing and inverting the slide so that none of the adhering brine is lost. In test trials this method, when properly handled, has been found to be as accurate as Lane's.

4. DIAGNOSIS BY VERMICIDAL TREATMENT

This method consists in the administration of a vermicide and the recovering of the expelled worms. All the stools passed by the patient for at least forty-eight hours should be saved and washed through a fine-mesh sieve and the worms identified and counted. The worms may also be separated by washing and decantation as they are heavier than feces and water. This technic has been used ex-

tensively in determining the relative value of different anthelmintics, intensity studies on hookworm infections and determining the worm index.

5. CULTURAL METHODS

The diagnosis of hookworm and *Strongyloides stercoralis* may be made by mixing equal amounts of feces with either bone black or sterile soil and incubating in a Petri dish at about 25° C. to 30° C. The diagnosis is made on the infective stages of these parasites. The infective stage of *Strongyloides* is developed after about thirty-six hours incubation at 25° C to 30° C., and usually five or six days at the same temperature are required for the hookworms. The infective larvæ of these worms may be successfully isolated with a modification of Baermann's technic. The apparatus consists of a nine-inch glass funnel almost filled with warm water and which has the outlet or stem closed by a clamped piece of rubber tubing. The culture is placed in a brass sieve, seven inches in diameter and three inches in height, which is fitted down into the funnel so that the level of the water is above the upper surface of the soil. To prevent small soil particles from sifting into the funnel, the sieve may be lined with one or two thicknesses of gauze. The preparation is allowed to stand for several hours, or over night, after which about 50 c.c. of water is run off into a centrifuge tube. This amount of water will contain the majority of the larvæ from the culture. The larvæ may be further isolated by centrifuging the tube or allowing the larvæ to sediment. The larvæ may be killed by the addition of a a few drops of 7.5 per cent solution of caustic soda which aids in their identification and microscopical study.

6. METHODS FOR COUNTING HELMINTH EGGS IN FECES

Recently a number of methods have been devised which do not primarily emphasize the presence or absence of ova but rather the determination of the number of ova, when present, as a clue to the severity of the infection. Two of the more successful of these methods are here given.

Stoll's method. The steps in Stoll's technic are as follows:

(1) Weigh by difference 3 grams of the feces into a large-sized tube or centrifuge tube graduated at 45 c.c.
(2) Add decinormal sodium hydroxide to the 45 c.c. level.
(3) Add ten small (3 mm.) glass beads, close with a rubber stopper and shake vigorously until a homogeneous suspension is obtained.

(4) Immediately transfer 0.15 c.c. of the suspension to the center of a 2 x 3 inch slide and cover with a 22 x 40 mm. No. 2 cover-slip.

(5) Count all the ova in the slide preparation with aid of a mechanical stage and a low power of the microscope. The number of ova found, multiplied by 100, represents the number of ova per gram of feces used.

Since the original method was devised, Stoll has made certain improvements in the technic which facilitate its operation. Special Pyrex Erlenmeyer flasks with marks at the 56 c.c. and 60 c.c. levels are used instead of test-tubes graduated at 45 c.c. The quantity of feces is also measured by displacement instead of weighing. The flasks are first filled with decinormal sodium hydroxide to the lower 56 c.c. mark and the feces are displaced until the diluent level reaches the upper 60 c.c. level. Samples of 75 cu. mm. are withdrawn from the suspension for the count instead of 0.15 c.c. as formely employed and a 25 mm. square cover-slip is used instead of the 22 x 40 mm. size. The average of two such counts is multiplied by 200 (rather than 100 as originally planned) to secure the number of ova per cubic centimeter, or the sum of two such counts may be multiplied by 100 to arrive at the same number. Other requirements in the original technic are not modified, such as thorough comminution of the specimen and adequate shaking before withdrawing the amount to be examined. This method has been found to yield average counts correct within less than 10 per cent of the absolute number of ova present in the fecal specimens. A relationship of approximately 1:2:4 has been found to exist in general between the formed, mushy (unformed) and diarrheic feces passed per day. This relationship affords an easy interpolation by which counts made on feces of any of these categories can be brought to a similar plane, the "basis of formed stools," for comparison. The number of eggs found in the specimen also reflects the degree of infection in numbers of worms harbored.

Stoll's method for counting ova has been widely used in various ways in field studies on hookworm control campaigns to determine the degree of infection of a given population. It has also been used in many experimental studies on the biology of the free-living stages of hookworms.

Caldwell's method. The principles emphasized in Stoll's technic form the basis for this method. Antiformin is, however, mixed with the feces which acts as a deodorant and a powerful germicide and also as a solvent of mucus and other gelatinous substances which may be present in the stool, which might so envelop the ova that an even suspension may be difficult to secure. Sugar solution of specific grav-

ity about 1.230 is used as the diluent. The various steps in the Caldwell technic are as follows:

(1) Weigh by difference 4 grams of feces and place in bottom of wide-mouthed tube calibrated to 40 mil.

(2) Add 4 mil. of antiformin (30 per cent strength of standard product) and mix feces and antiformin with small glass rod. Leave stirring rod in position and let mixture stand at room temperature for one hour.

(3) Add sugar solution of specific gravity about 1.230 to the 40 mil. mark.

(4) Remove glass rod after a preliminary stirring and secure an even suspension by bubbling through bacteriological pipette placed against the bottom of tube.

(5) With bacteriological pipette withdraw 0.1 mil. of the suspension.

(6) Deposit 0.1 mil. sample on glass slide and with small rod with fine point, spread sample to make a small, flat square or rectangular film. No cover-slip is necessary.

(7) Count eggs with aid of mechanical stage and the lower power of a microscope and multiply the number of ova found by 100 to express the number of ova per gram of feces.

III. *The Examination of Urine for Helminth Eggs*

The urine is examined usually for determining the presence of *Schistosoma hæmatobium.* Other helminths, mostly incidental in nature, infecting the urinary system may also be detected by such an examination.

The specimen of urine is allowed to stand for several hours or over night in a sedimentation jar. The ova, if present, are thus concentrated in the sediment which can be transferred easily to a glass slide for microscopical examination. For a rapid diagnosis the ova may be concentrated by centrifuging a portion of the urine after it has been thoroughly stirred.

IV. *Method for Examining Blood for Microfilariæ*

Six or eight large drops of blood are allowed to drop from the tip of the finger onto an ordinary clean slide and is evenly spread before clotting over the surface of the slide. The blood films are dried in a level position, protected from insects and dusts, but should be freely exposed to the air. They are then dehemoglobinized in water in order to get a colorless film and when the laking of the hemoglobin is complete, the slides are examined while still wet on a mechanical stage and under a low power of the microscope. The microfilariæ, if present, appear as glistening objects and are readily distinguished.

For morphological study and identification of the microfilariæ the dehemoglobinized preparations may be stained with Delafield's hemotoxylin for five minutes, steaming the stain over a flame as in staining tubercle bacilli, and then washed in tap water. They should then be differentiated momentarily in acid alcohol, washed again in tap water until blue, dehydrated in absolute alcohol, cleared and mounted in Canada balsam. In obtaining the blood for the examination it should be remembered that some microfilariæ may be found only in the peripheral blood either during the night or daytime, according to the species.

Section III

MEDICAL ENTOMOLOGY

BY

FRANCIS M. ROOT

CHAPTER XXXIII

INTRODUCTION

I. *Medical Entomology*

Medical Entomology may be defined as the study of those Arthropods which carry or cause diseases in human beings. There are two points in this definition which deserve a little further discussion.

In the first place, since Entomology is the study of insects, it may seem strange that Medical Entomology is not defined as the study of insects which are concerned in the causation or transmission of human diseases. But it happens that there are certain other Arthropods which are related to insects and which carry or cause diseases in very much the same manner as insects, and these forms, particularly the ticks and mites, may most conveniently be included in Medical Entomology, although they are not true insects. The phylum ARTHROPODA, consisting of invertebrate animals with paired, jointed appendages on the segments of the head, the thorax and sometimes the abdomen and with a chitinous exoskeleton, is divided into the following five classes:

Class INSECTA (true insects)
Class ARACHNIDA (ticks, mites, spiders, scorpions, etc.)
Class CRUSTACEA (crabs, lobsters, shrimps, water-fleas, etc.)
Class MYRIAPODA (centipedes and millipedes)
Class PROTRACHEATA (Peripatus)

The forms which are of medical importance include especially several types of true insects and certain ticks and mites, but one might also treat under the head of Medical Entomology those spiders, scorpions and centipedes whose bites or stings can produce symptoms in human beings and the crabs and water-fleas (Cyclops) which act as intermediate hosts for helminth parasites of man.

The insects and other Arthropods which parasitize wild and domestic animals or transmit their diseases belong rather to Veterinary than to Medical Entomology, but it is often desirable to mention them

in connection with the related forms which are of medical importance, both because they often offer convenient material for laboratory work and because much may be learned about the carriage of human parasites by a study of the transmission of related parasites of the lower animals. This last fact was beautifully illustrated by the discovery of the transmission of malaria by mosquitoes, resulting from studies made by Sir Ronald Ross, mainly on the related malaria parasites found in birds.

The other point in our definition of Medical Entomology which deserves further emphasis is the presence of the word *carry,* which introduces a new aspect of Parasitology. In Protozoölogy, Helminthology and Bacteriology one is dealing with forms of life which enter the human body and may cause disease there. Some few Arthropods behave in the same way, but the main importance of Medical Entomology is due to the fact that certain Arthropods which do not themselves cause diseases do *transfer* from one man to another or from lower animals to man the protozoa, helminths or bacteria which cause diseases. In many of these cases the easiest way to get rid of the disease is to control, not the disease-producing organism, but the insect vector. This, of course, makes the study of Medical Entomology of great practical value.

While there is no doubt of the advisability of including Medical Entomology as one of the divisions of Parasitology, there may be much discussion as to whether we can, strictly speaking, call these insect vectors *Parasites.* In the last analysis, the difficulty lies in defining how long an organism must remain on its host to be called a parasite. In the first chapter of this book we have defined a parasite as an organism that lives on, in or with some other living organism from which it derives some benefit, and have recognized as periodic parasites those parasites which make short visits to their hosts to obtain nourishment or other benefits. The question is, how long must these visits last? At first glance one would probably declare that a tick was undoubtedly a parasite, but a mosquito was not. And yet most ticks behave toward their hosts exactly as does a mosquito. Both attach themselves to the host by piercing its skin with their mouthparts and, if not disturbed, remain attached until they have filled themselves with blood. The difference is that while the mosquito can engorge in a few minutes, the tick must remain for days or even weeks before engorgement is complete. In either case, however, when filled with blood the Arthropod leaves its host and digests the blood-meal and lay its eggs in a free-living condition.

II. *External Structure of Insects*

Insects are completely enclosed in a non-cellular integument which is more or less chitinized and which is often called the exoskeleton, since it performs both the protective function of a skin and the supporting function of a skeleton. In order to permit freedom of movement this integument is not uniformly chitinized throughout, but consists of a number of hard plates or *sclerites,* connected with each other by flexible, slightly chitinized membranes.

Insects are supposed to have developed from ancestors more or less resembling the segmented worms, and in the beginning the insect body probably consisted of a large number of similar segments, each with a pair of jointed appendages. In the insects of the present time, however, the segmentation is obvious only in the abdomen and the division of the body into the three regions of head, thorax and abdomen is much more important than the original segmentation.

The head consists of a box-like capsule formed, as we can see if we study insect embryology, by the complete fusion of seven original segments. The appendages of these segments are retained, for the most part, and form the antennæ or feelers, the compound eyes, and the mouth parts, which usually include a pair of mandibles, a pair of maxillæ and a labium formed by the fusion of a pair of maxilla-like appendages. The maxillæ and the labium may have sensory *palpi* attached to them. The structure of the mouth parts varies a great deal, depending upon the type of food taken by the insect. From one to three ocelli or simple eyes may be present on the dorsum of the head in addition to the compound eyes.

The thorax consists of three segments (prothorax, mesothorax and metathorax), which may or may not be fused together. The appendages of these three segments are the legs, each made up of a number of joints (called, proceeding from base to tip, coxa, trochanter, femur, tibia and several [usually five] tarsal joints). In addition to the legs, the mesothorax and metathorax each have a pair of wings in most insects. This is not always true, for in the Order DIPTERA, so important from the medical viewpoint, the metathoracic wings are always reduced to tiny rudiments of no value in flight, and in ectoparasitic insects like fleas and lice wings are entirely absent.

The size and degree of development of the thoracic segments depends a great deal upon the development of the wings. In wingless forms like the fleas the three thoracic segments are all small and about

the same size. In winged insects the prothorax is often smaller than the other two segments and in the flies or DIPTERA, the mesothorax, bearing the only functional wings, is very large, while both prothorax and metathorax are much reduced in size.

Each thoracic segment has chitinized plates or sclerites dorsally, laterally and ventrally. If there is only one in each region the dorsal sclerite is called the *notum,* the ventral one the *sternum* and each of the lateral ones a *pleuron.* Often these sclerites are more or less distinctly divided into several portions by scars or *sutures,* at least in one or two of the thoracic segments. The notum may be divided into *pre-scutum, scutum, scutellum* and *postscutellum.* The pleuron is usually divided into an anterior *episternum* and a posterior *epimeron,* but in most of the DIPTERA the very large meso-thoracic segment has these sclerites still further divided, the episternum being separated into a dorsal *meso-pleura* and a ventral *sterno-pleura,* the epimeron into a dorsal *pteropleura* and a ventral *hypopleura.* The sternum is usually a single plate but may be divided into *sternum and sternellum* in some insects.

While the head of an insect is a special region bearing sense organs and mouth parts and the thorax is a region specialized for bearing locomotor appendages, the abdomen is not a specialized region but only the remaining segments of the body. The number of segments in the abdomen varies in different insects, but the usual number appears to be ten. The last one or two segments are usually somewhat modified for sexual purposes, forming the external genitalia or *hypopygium* of the male and the *ovipositor* of the female. Each abdominal segment usually has a single dorsal sclerite (*tergite*) and a single ventral sclerite (*sternite*) connected at the sides by *pleural membranes.* In most insects, the appendages of the abdominal segments are absent except in the terminal segments which are modified for copulation and oviposition.

III. *Internal Structure of Insects*

Internally insects differ most strikingly from vertebrates in the position of the nervous system, the development of the circulatory system and the method of functioning of the respiratory system.

The nervous system consists of a chain of ganglia, connected by commissures, lying ventrally, just inside the ventral body wall. Originally there was one ganglion or pair of ganglia for each body segment, but in present-day insects the seven head ganglia have fused into two and the abdominal ganglia are usually reduced in number

because a certain amount of fusion has taken place in that region also. Besides the two main ganglia of the head there are usually a large pair of optic ganglia in close connection with the compound eyes. Usually the three thoracic ganglia are larger than the head ganglia. From each ganglion nerve strands are given off to the adjoining tissues and appendages.

There is no well-developed circulatory system in insects. The blood fills the body cavity (*hæmocœle*) and is kept more or less stirred up by the pulsations of a single dorsal vessel which takes in blood posteriorly and ejects it anteriorly.

The respiratory system consists of a branching system of internal air-tubes (*tracheæ*) which open to the exterior through one or more pairs of *spiracles* and carry air directly to all tissues of the body. There is a pair of large tracheæ running the full length of the body and communicating with the spiracles either directly or by short side-branches. From the large tracheal trunks are given off smaller tracheæ which branch again and again until the ultimate branches or tracheal capillaries reach all the cells of the body. In some aquatic insect larvæ the tracheal system is open to the air, as in the adults; in others the tracheal system is closed and oxygen is obtained from the water by means of *tracheal gills,* much like blood-gills in their structure except that the capillaries are represented by fine tracheæ.

The digestive system is well-developed, but a large part of it consists of invaginated ectodermal tissue. Only the stomach or *ventriculus* is endodermal. Salivary glands are usually present, but are not connected with the digestive system except for the fact that their duct ends in connection with the mouth parts. In some insects a *crop* for the storage of food is present.

Excretory organs are represented by a variable number of *Malpighian tubules,* which are attached to the alimentary canal just about at the point of junction of ventriculus and intestine.

The reproductive system is comparatively simple. There are a pair of testes or ovaries, whose ducts soon unite to form a common duct leading to the genital opening. The male may have accessory glands and a seminal vesicle for the storage of spermatozoa and the female may have shell glands, cement glands, and a seminal receptacle.

In the abdomen is found a loosely connected tissue of large cells called the *fat-body,* which may be very prominent in insects entering upon hibernation and presumably represents a reserve food supply.

IV. *Life Histories of Insects*

All insects produce eggs, although in some insects the eggs hatch within the body of the female. In the more primitive insects, grasshoppers or bugs for example, the *larva* which hatches from the egg closely resembles the parent except in size, proportions and the absence of wings and reproductive organs, and takes the same food as the adult. As the larva grows it has to shed its skin or *moult* at intervals, finally becoming an *adult* with functional wings and sex organs after the last moult. Such a life history is said to be a case of *incomplete metamorphosis,* since there is no striking change in appearance when the larva becomes an adult.

In the more highly specialized insects, such as butterflies or flies, on the other hand, the larva which hatches from the egg is a worm-like organism which looks very different from its parent and has entirely different food-habits. As this larva grows and moults several times it retains essentially the same appearance until, at the next to the last moult, it suddenly changes into an enclosed or protected *pupa,* which does not feed, but again sheds its skin to liberate the adult after a variable interval. Such a life history is said to exhibit *complete metamorphosis,* since there is a complete change in appearance in passing from the larva to the adult. Although some pupæ (those of mosquitoes, for example) are quite active, most pupæ are relatively or entirely quiescent, so that the pupa is sometimes spoken of as a resting stage. This is true, superficially, but if we were to look into the inside of the pupa we would find it a period of intense activity, during which almost all of the larval structures are broken down and the structures of the adult built up. This seems to be, in fact, the reason for the pupal stage. The larvæ of these specialized insects have become so different from the adults, in adaptation to their different habitat and food, that they are no longer able to change directly into the adult by shedding their skins and have to take this externally quiescent pupal period to concentrate upon the task of remodelling all their structures for an entirely different sort of life.

The fact that insect larvæ are completely enclosed by a more or less chitinized integument which must be shed or moulted periodically in order to permit of growth, is often very convenient for the entomologist in studying life histories. In the case of mosquitoes, for example, it is easily possible to isolate a larva and preserve for study the larval skin, the pupal skin and the adult mosquito. The larval and pupal skins retain all their characteristic hairs and

other appendages and are often even better material than preserved larvæ or pupæ for the study of their structure and distinguishing characteristics. They also have, of course, the additional advantage that one may be sure of studying the larval, pupal and adult structures of the same individual specimen.

CHAPTER XXXIV

THE DIPTERA (FLIES, MOSQUITOES, ETC.)

I. *Importance*

Of all the groups of arthropods which are of interest to medical entomologists the order DIPTERA, or true flies, are of paramount importance. This order includes a great variety of blood-sucking forms, including the only vectors of such important diseases as malaria, yellow fever and African sleeping sickness, and also contains a number of non-blood-sucking forms of sanitary interest, such as the ordinary house-flies and blow-flies.

II. *Characteristics*

The most characteristic thing about the DIPTERA is that only one pair of wings (the fore wings) is functional, the hind wings being reduced to tiny club-like structures known as the *halteres*. In consequence of this, the mesothorax, bearing the functional wings, is enlarged dorsally at the expense of the other two thoracic segments, so that in dorsal view nearly all the visible parts of the thorax belong to this segment.

The mouth parts of the DIPTERA are always adapted for sucking up liquids, but their structure varies a great deal in different groups and sometimes even in the two sexes of the same species. Some forms feed on vertebrate blood, others on the blood and body juices of other insects, and many more on the nectar of flowers or on any exposed food substance which is in a liquid state or can be liquefied by the regurgitation of fluid from the fly's crop.

In the more primitive DIPTERA, such as horse-flies or mosquitoes, the mouth parts include paired *mandibles* and *maxillæ* and an ensheathing *labium,* as well as two other structures, the *epipharynx* and the *hypopharynx,* which together form a tube through which blood or other liquids can be sucked up. The hypopharynx also contains the salivary duct, which opens at its tip. A pair of *palpi* are attached to the bases of the maxillæ, but in the DIPTERA labial palpi are never present. As we run through a series of families in the

DIPTERA we find first the mandibles and then the maxillæ reduced and then entirely absent until in the most highly developed DIPTERA, such as the house-flies and tsetse-flies, the mouth parts include only labium, epipharynx, hypopharynx and the maxillary palpi, which are now attached to the base of the labium.

III. *Classification*

In classifying the DIPTERA, that is, in arranging the various different forms in a natural evolutionary series, we make use of several different tendencies which may be seen in the group. The first division depends on the structure of the larva and pupa. In the suborder

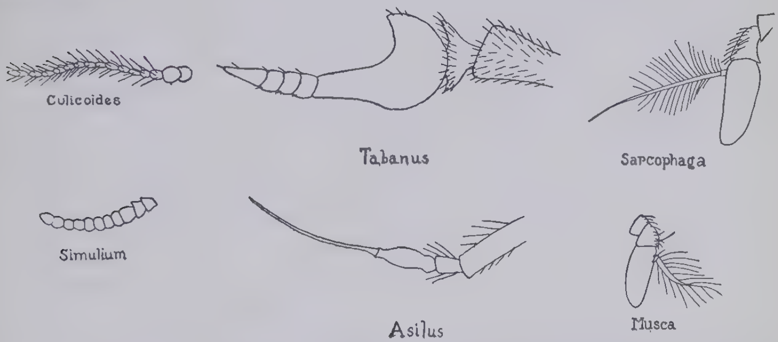


FIG. 224.—Antennæ of Diptera; *Culicoides* and *Simulium* representing the Nematocera, *Tabanus* and *Asilus* the Brachycera, and *Sarcophaga* and *Musca* the Cyclorrhapha. (Original. Root)

ORTHORRHAPHA the larva has a well-chitinized head capsule and the pupa is enclosed in its own heavily chitinized pupal skin. The adult escapes from the pupal skin by a longitudinal dorsal slit in the thoracic region. In the more specialized suborder CYCLORRHAPHA the larval head is not enclosed in a chitinized capsule and the pupa, whose own skin is not well chitinized, is enclosed and protected by a *puparium* formed by strengthening the last larval skin by a further deposit of chitin. The adult escapes from the puparium by pushing off a circular cap at the anterior end by repeated protrusions of a fluid-filled vesicle, the *ptilinum,* which projects from the anterior surface of the head of the adult, just above the bases of the antennæ. After the adult has emerged the ptilinum is withdrawn within the head, leaving only a scar to mark the place where it was evaginated. In some flies with a small ptilinum this scar is only a crescent-shaped affair above the bases of the antennæ (the *frontal lunule*).

In others where the ptilinum is larger, the scar is continued ventrally on each side of the depression in which the antennæ lie, these continuations being called the *frontal sutures.*

Although this division of the order DIPTERA into two suborders is a fundamental one for classification, it is not a very convenient one to use in identifying specimens. For identification it is easier to make use of the tendencies toward reduction or simplification which appear in the structure of the antennæ and the venation of the wings.

In the antennæ, the most primitive forms have long antennæ composed of a considerable number of elongated joints. As we pass to higher and higher forms we find the joints becoming shorter and thicker and the number of joints reduced, until in the higher flies we reach a standardized condition in which the antennæ consist of

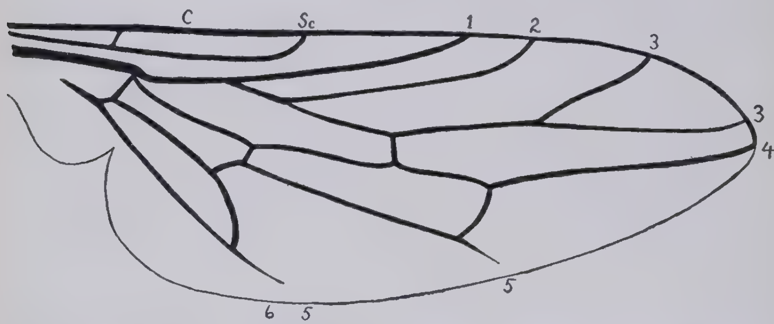


FIG. 225.—Wing venation of *Scenopinus;* C, costa; Sc, subcosta; 1 to 6, first to sixth veins. (Original. Root)

two short basal joints and a larger third joint from whose dorsal side near the base there arises a slender filament, the *arista,* which probably represents several joints fused together (see Figure 224).

The wing venation also offers very convenient characters for identifying flies. Along the front edge of the wing there runs a strong vein, the *costa,* which may extend entirely around the wing margin or may end abruptly at or before the tip of the wing. Just behind the costa lies another vein, the *subcosta,* which usually joins the costa somewhere along the anterior margin of the wing. Behind the subcosta come a series of six more longitudinal veins which are simply called the first, second, third, fourth, fifth and sixth veins. The first, fourth, fifth and sixth veins arise at the base of the wing, but the second and third do not. In many wings it can be seen that the second vein arises as a branch of the first and the third vein as a branch of the second, but in such a wing as that of a mosquito, for

example, this is not always obvious. The longitudinal veins are joined to each other by a small number of short *cross-veins*. Beneath the base of the wing are often found rounded, membranous prolongations extending posteriorly and called the *squamæ*.

In passing from lower to higher groups of DIPTERA, we find that the tendency of evolution in the order is toward a reduction in number of veins produced by the fusion of adjoining veins, beginning at their tips. This process may be appreciated best by comparing the positions of the sixth vein and the posterior branch of the fifth in the wings of *Anopheles, Chrysops, Scenopinus,* and *Musca* (Figures 227, 246, 225 and 249).

The legs of DIPTERA are of the usual insect structure, with five tarsal joints. The last joint usually bears at its tip two *claws* and often two hairy pads or *pulvilli*. Ventrally, in the mid-line, we often find an *empodium,* which is usually a branched or unbranched bristle-like structure, but sometimes forms a third hairy pad like the pulvilli.

The following tabulation will show the general scheme of classification of the Order DIPTERA and the position in it of those families which contain species of importance to medical entomologists.

- Order DIPTERA
  - Suborder ORTHORRHAPHA
    - Section NEMATOCERA—CULICIDÆ—Mosquitoes
      - CHIRONOMIDÆ—Midges
      - PSYCHODIDÆ—Moth-flies
      - SIMULIIDÆ—Black-flies
    - Section BRACHYCERA—TABANIDÆ—Horse-flies
  - Suborder CYCLORRHAPHA
    - Section ASCHIZA—SYRPHIDÆ—Flower-flies
    - Section SCHIZOPHORA
      - Tribe ACALYPTERÆ
      - Tribe CALYPTERÆ—ŒSTRIDÆ—Bot-flies
        - SARCOPHAGIDÆ—Flesh-flies
        - CALLIPHORIDÆ—Blow-flies
        - MUSCIDÆ—House-flies
        - ANTHOMYIDÆ
    - Section PUPIPARA—HIPPOBOSCIDÆ—Tick-flies

In the following key I have attempted to give sufficient information to enable the student to distinguish the families which contain species of medical importance, but have left unmentioned a number

of families of flies which are of no interest from the medical viewpoint.

KEY TO THE FAMILIES OF DIPTERA WHICH ARE OF MEDICAL INTEREST

1. Abdomen distinctly segmented; wings usually present.......... 2
   Abdomen sac-like, without distinct segmentation; wings sometimes reduced or absent...........CYCLORRHAPHA PUPIPARA 17
2. Antennæ long and composed of more than six joints; tips of sixth vein and posterior branch of fifth widely separated ............................ORTHORRHAPHA NEMATOCERA 3
   Antennæ short and composed of three or four joints; the last joint may be simple or divided into annuli and, if simple, may have either a terminal bristle or a dorsal arista; tips of sixth vein and posterior branch of fifth close together or fused.... 7
3. Wing venation well-developed, so that nine or more veins or branches of veins reach the margin of the wing............ 4
   Wing venation reduced, so that less than nine veins or vein branches reach the wing margin......................... 6
4. Wings without cross-veins except near base........*Psychodidæ*.
   Wings with one or more cross-veins at or beyond middle of wing 5
5. Ocelli absent; mesonotum divided into scutum, scutellum and postscutellum; no extra seventh vein present in the wing .... *Culicidæ*.
   Ocelli present (*Rhyphidæ*) or mesoscutum divided into prescutum and scutum by a V-shaped suture and usually a seventh vein present in the wing ....(*Tipulidæ*).
6. Short, stout flies with stout antennæ which do not bear circlets of long hairs on most of the segments ....*Simuliidæ*.
   Usually more slender flies; antennæ slender, with circlets of long hairs on most of the segments, this being especially noticeable in the males ....*Chironomidæ*.
7. Third vein forked; antennæ projecting anteriorly; frontal lunule and frontal sutures always absent ..............................ORTHORRHAPHA BRACHYCERA 8
   Third vein not forked; antennæ usually bent downward; frontal lunule present and often frontal sutures also...CYCLORRHAPHA 9
8. Last joint of antenna divided into from four to eight annuli; squamæ large; discal cell of wing longer than broad .... *Tabanidæ*.
   Last joint of antenna not divided into annuli (many families, including *Asilidæ*, *Leptidæ*, *Bombyliidæ*) or else squamæ small or discal cell of wing small and as broad as long .... (*Stratiomyidæ*).
9. Frontal lunule present; frontal sutures absent ................................CYCLORRHAPHA ASCHIZA 10
   Frontal lunule and frontal sutures both present ............................CYCLORRHAPHA SCHIZOPHORA 11
10. A false vein in wing between third and fourth veins and parallel to them ....*Syrphidæ*.
    No false vein in wing ....(*Pipunculidæ*).

11. Squamæ small or rudimentary; subcosta often reduced (ACALYPTERÆ—many families, including *Drosophilidæ, Sepsidæ, Scatophagidæ*).
    Squamæ large; subcosta always well developed......CALYPTERÆ 12
12. Mouthparts reduced; mouth opening small............*Œstridæ*.
    Mouthparts well developed; mouth opening large............... 13
13. A row of strong bristles on the hypopleura 14
    Hypopleura bare or with fine hairs 16
14. Postscutellum with a double convexity; abdomen very bristly ....(*Tachinidæ, Dexiidæ*).
    Postscutellum with a single convexity; abdomen bristly only near tip 15
15. Antennal arista plumose for only about half its length; body usually gray and black ....*Sarcophagidæ*.
    Arista plumose nearly to tip; body usually metallic bluish or greenish ....*Calliphoridæ*.
16. Tip of fourth vein straight ....*Anthomyidæ*.
    Tip of fourth vein angled or curved toward the third vein .... *Muscidæ*.
17. Head not folding back onto dorsum of thorax; palpi not broad and leaf-like; ectoparasitic on birds and mammals .... *Hippoboscidæ*.
    Head folding back onto dorsum of thorax (*Nycteribiidæ*) or palpi broad and leaf-like (*Streblidæ*); both ectoparasitic on bats only.

CHAPTER XXXV

FAMILY CULICIDÆ—SUBFAMILY CULICINÆ—TRUE MOSQUITOES

I. *Characteristics*

The family CULICIDÆ is made up of the subfamily CULICINÆ (true mosquitoes) and two other subfamilies, the DIXINÆ and CHAOBORINÆ (or CORETHRINÆ), which include species resembling mosquitoes in many respects but not blood-sucking in habit and without medical significance.

The true mosquitoes (subfamily CULICINÆ) may be distinguished from all the other small flies which superficially resemble them by the following combination of characters: (a) wing venation as in Figure 227, (b) mouth parts or *proboscis* much longer than the head, (c) longitudinal veins and posterior border of wings fringed with flat, striated scales. Some TIPULIDÆ, for example, have long probosces, and some of the CHAOBORINÆ resemble mosquitoes in the venation and scalation of the wings, but only the true mosquitoes exhibit the combination of all three of these characteristics.

II. *Structure of Adult*

The head of a mosquito bears five prominent appendages, two antennæ, two palpi and a proboscis (see Figure 229). Each antenna consists of a small ring-like basal joint, a large, bulbous second joint or *torus,* and thirteen *flagellar joints,* all slender and elongate. Each of the flagellar joints bears a circlet of hairs, which are comparatively short in females, but very long in most male mosquitoes. The bushy, plumose antennæ of the males make it easy to distinguish the sexes of mosquitoes. The palpi (really, of course, maxillary palpi) consist of from three to five joints in different species and sexes of mosquitoes. They may be very short or longer than the proboscis and these differences in length are very important in differentiating the malaria-carrying mosquitoes from the other species. The proboscis is always much longer than the head and is usually straight. What we see of the mosquito's proboscis is really the en-

sheathing labium, which has a deep groove on its dorsal surface. In the female mosquito six slender stylets lie in this groove, representing a pair of mandibles, a pair of maxillæ, an epipharynx and a hypopharynx. When the mosquito bites it is only the stylets which pierce the skin, the labium remaining outside and being bent into the shape of a U as the stylets penetrate more deeply. In the male mosquitoes

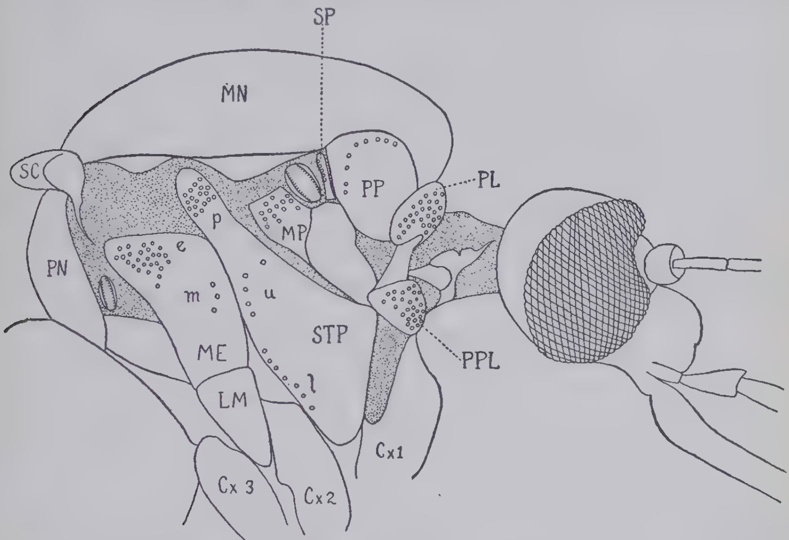


FIG. 226.—Lateral view of the thorax of *Psorophora,* to show the locations of sclerites and groups of bristles. The position of the bristles is indicated by tiny circles, representing the scars which they leave when removed. SC, scutellum; PN, postnotum; PL, prothoracic lobe; MN, mesonotum; PPL, propleura (bearing propleural bristles); PP, posterior pronotum (bearing pronotal bristles); SP, spiracular sclerite (bearing spiracular bristles); MP, mesopleura (bearing post-spiracular bristles); STP, sternopleura (bearing p, pre-alar bristles; u, upper sternopleural bristles; and l, lower sternopleural bristles); ME, mesepimeron (bearing e, upper mesepimeral bristles; and m, mid mesepimeral bristles); LM, lateral metasternal sclerite; Cx1, Cx2, Cx3, coxæ of first, second and third legs. (Original. Root)

the piercing stylets (mandibles and maxillæ) are usually absent, leaving only the epipharynx and hypopharynx. For this reason male mosquitoes are actually incapable of biting.

The thorax of a mosquito is composed of a number of sclerites, most of which belong to the middle thoracic segment. The presence or absence of groups of bristles on various sclerites of the thorax are much used at present as characters for differentiating the various genera. Figure 226 shows a lateral view of the thorax of a mosquito with the names usually applied to the sclerites and the groups of bristles which they bear. The thorax bears one pair of functional wings and three pairs of legs.

The venation of a mosquito wing is shown in Figure 227. There is comparatively little variation in different species. The costa extends all around the wing, although in speaking of the costa or the costal region of the wing we usually mean only that part of the costa which forms the anterior border of the wing, from the base of the wing to the tip of the first vein. The subcosta and the first, third and sixth veins are not forked. The second, fourth and fifth veins are forked. Cross-veins seem to be present connecting the costa and subcosta, the subcosta and the first vein, the first and second veins, the second and third veins, the third and fourth veins and the fourth vein and the anterior branch of the fifth. The apparent cross-veins connecting the first vein to the second and the second to the third

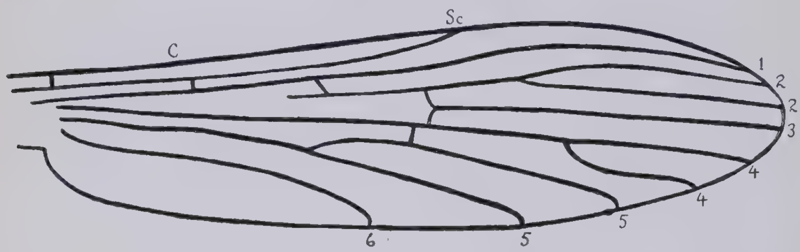


FIG. 227.—Wing venation of *Anopheles*. C, costa (costa); Sc, subcosta (subcosta); 1, first vein (Radius-one); 2,2, second vein (Radius-two and Radius-three); 3, third vein (Radius-four plus five); 4,4, fourth vein (Media-one and Media-two); 5,5, fifth vein (Cubitus-one and Cubitus-two); 6, sixth vein (Anal). (Original. Root)

often look just like the other cross-veins, but are really the bases of the second and third veins, which arise as branches of the first and second veins, respectively. The spaces between the forks or branches of the second and fourth veins are often called the *first* and *second fork cells,* and those parts of the second and fourth veins which lie between their bifurcations and the cross-veins connecting them with the third vein are termed the *stems* or *petioles* of the fork cells.

In the key to adult mosquitoes of the tribe CULICINI it will be noticed that the shape of the individual scales of the wing must often be studied. The presence or absence of bristles and hairs on the *base of the first vein* (that part of the first vein which lies between the base of the wing and the *humeral cross-vein* connecting the costa and subcosta) is also of considerable importance.

In the legend for Figure 227 are given both the terminology of the veins used in this book and also another system invented by Comstock and Needham and used by many authors. The latter names are placed in parentheses.

The legs of a mosquito are long and slender and of the type usual in the DIPTERA, with five tarsal joints. Sometimes the first tarsal joint is called the metatarsus, but usually the tarsal joints are simply referred to as first, second, third, fourth and fifth, the first being the one which is attached to the tibia and the fifth the terminal joint which bears the claws. For brevity it is often convenient to omit the word joint or segment, thus if we speak of the first hind tarsal we mean the joint next to the tibia on the hind leg.

The abdomen of a mosquito is long and slender and consists of ten segments, of which eight are well developed and easily seen, while the last two are modified for sexual purposes. The last segment of the female abdomen bears a pair of short *cerci,* while in the male the last two segments and their appendages form the external genitalia or *hypopygium.* The numerous modifications of the male hypopygium are of great value in classifying and even in identifying mosquitoes, but are not convenient for field work and cannot be treated in detail in a book of this size.

III. *Life History*

The female mosquito lays her eggs either on or in water or in situations which will be covered with water at some later time. Mosquito larvæ are usually found only in water, although they may survive for a few days in merely moist surroundings. The larval stage lasts for some time. It is the growth period of the mosquito. This growth necessitates a periodic moulting or shedding of the skin of the larva. These moults divide the larval life of a mosquito into four periods or stages, leading us to speak of larvæ as being in the first, second, third or fourth larval stage. Since the hairs and other structures which are used in identifying mosquito larvæ usually differ in different larval stages, descriptions of mosquito larvæ and keys for identifying them usually refer only to the full-grown or fourth-stage larvæ.

When the fourth-stage larva moults, there emerges a comma-shaped pupa, which is very active but takes no food. After a few days the pupa comes to the surface of the water and its skin splits open dorsally to liberate the adult, which remains for a short time on the raft formed by the air-filled pupal skin and then flies off. Mating between the sexes probably occurs in nature soon after the emergence of the females. In some species, the yellow-fever mosquito for example, mating occurs readily in the laboratory. In other species, such as the malarial mosquitoes, it is usually very difficult to obtain

mating in captivity, probably because the males of these species normally form mating swarms which hover in sheltered places awaiting the coming of the females.

IV. *Structure of Larvæ*

A mosquito larva is a worm-like creature without legs or wings. Its head is enclosed in a chitinized capsule, but the large unsegmented thorax and the nine-segmented abdomen are covered for the most part by a membranous integument. The head bears compound eyes and antennæ dorsally and the mouthparts ventrally. In addition to *mandibles, maxillæ* and *labium* a mosquito larva also has a pair of large hairy structures, the *mouth brushes,* which project anteriorly beyond the anterior margin of the head. These are used by most mosquito larvæ to create currents in the water which bring the small floating plants or animals on which they feed to the mouth. Some few mosquito larvæ feed on the larvæ of other mosquitoes, and in these each hair of the mouth brushes is converted into a stiff comb-like structure which aids it in securing a firm grip on its victims.

The head, thorax and abdominal segments of mosquito larvæ all bear numerous paired hairs, whose form and position vary in different species and are used in identifying the larvæ. The region of the body which is most important in identifying mosquito larvæ is the tip of the abdomen. The openings of the respiratory system of the larva are situated dorsally on the next to the last abdominal segment. In all mosquito larvæ except those of *Anopheles,* the actual openings are at the tip of the more or less elongated, chitinized *air-tube,* which projects dorso-posteriorly. The air-tube has one or more pairs of ventral hairs or *hair-tufts* and usually bears also a row of spines, called the *pecten,* on each side, ventrally, near its base. In larvæ of *Anopheles* the air-tube is rudimentary and consists only of a ribbon-like chitinization which is triangularly expanded at each end to bear the *pecten* (often called the *comb* in descriptions of *Anopheles* larvæ). The true *comb* is present laterally on the eighth abdominal segment of nearly all other mosquito larvæ and even in the first-stage or newly-hatched larvæ of *Anopheles.* It consists of a line or triangular patch of *comb-scales* which are often more or less fringed with spinules and may or may not be attached to the posterior margin of a chitinized plate.

The ninth or anal segment of the abdomen of a mosquito larva is usually more slender and elongate than the other segments. It is usually more or less completely encircled by a chitinous *plate.* The

anus is at the tip of the ninth segment and around it arise four transparent, usually sausage-shaped structures, the *anal gills*. The ninth segment also bears at its tip two pairs of *dorsal* and one pair of *lateral hairs* or *hair-tufts*. In most mosquito larvæ there is also a line of unpaired, mid-ventral hair-tufts, which are referred to as the *ventral brush*.

As has been noted above, the respiratory system of a mosquito larva has external openings and the great majority of mosquito larvæ have to come to the surface of the water periodically for air. In the larvæ of a few species, however, the anal gills are unusually large and the larvæ rarely if ever come to the surface, so that it seems probable that they are able to extract what oxygen they need from the water by means of these gills. In the genus *Mansonia*, moreover, the larvæ thrust the sharp tips of their air-tubes into the air-containing tissues of certain aquatic plants and thus escape the necessity of coming to the surface for air.

V. *Structure of Pupæ*

In the mosquito pupa, the head and thorax are fused into a single roundedly triangular mass from which projects the elongate, curved, segmented abdomen, ending in a pair of leaf-like *paddles*. On the sides of the main mass may be seen the cases which contain the antennæ, wings and legs of the adult. The respiratory system opens to the exterior through two more or less tubular *breathing trumpets*, which arise near the mid-dorsal region of the thorax. Since pupæ usually yield adults within a few days it is not so important to be able to identify pupæ as it is in the case of larvæ, but the pupæ do offer characters by which they may be distinguished. The shape of the breathing-trumpets and of the paddles at the tip of the abdomen, and the hairs and hair-tufts on the abdominal segments are particularly valuable for this purpose.

VI. *Classification of Mosquitoes*

According to the latest revision of American mosquitoes, the subfamily CULICINÆ is divided into five tribes. Two of these tribes, the ANOPHELINI and the CULICINI, include species which are disease carriers and others which are important pests. The other tribes, the MEGARHININI, URANOTÆNINI and SABETHINI, are of very little importance from the medical point of view.

The following key to tribes by adult characters is adapted from

one given by Dyar and Shannon (1924). A key by larval characters is also presented.

KEY TO TRIBES OF CULICINÆ BY ADULT CHARACTERS

1. Base of hind coxa in line with upper margin of lateral metasternal sclerite; spiracular bristles not absent if pronotal bristles are present 2
   Base of hind coxa distinctly below upper margin of lateral metasternal sclerite (except in *Hæmagogus*, in which spiracular bristles are absent and pronotal bristles present) 3
2. Clypeus much broader than long; posterior margin of scutellum evenly rounded; postnotal bristles absent........*Megarhinini.*
   Clypeus at least as long as broad; posterior margin of scutellum tri-lobed; postnotal bristles usually present........*Sabethini.*
3. Palpi of female as long as proboscis; posterior margin of scutellum evenly rounded (except in *Chagasia*)........*Anophelini.*
   Palpi of female very short; posterior margin of scutellum tri-lobed 4
4. Sixth vein of wing ending opposite fork of fifth vein or basal to it; wing membrane without minute hairs........*Uranotænini.*
   Sixth vein extending well beyond fork of fifth vein; wing membrane covered with minute hairs.................*Culicini.*

KEY TO TRIBES OF CULICINÆ BY LARVAL CHARACTERS

1. Air-tube well developed 2
   Air-tube rudimentary, practically absent...........*Anophelini.*
2. Anal segment with a median ventral brush 3
   Anal segment with a pair of sub-ventral hair-tufts....*Sabethini.*
3. Eighth segment with lateral plate but without comb-scales; air-tube without pecten ....*Megarhinini.*
   Eighth segment with or without lateral plate, but always with comb-scales; air-tube with or without pecten 4
4. Head longer than broad; eighth segment with lateral plate bearing comb-scales on its posterior margin........*Uranotænini.*
   Head as broad as long or broader; eighth segment with or without lateral plate; comb-scales may or may not be attached to this plate if it is present ....*Culicini.*

CHAPTER XXXVI

TRIBE ANOPHELINI—THE MALARIAL MOSQUITOES

I. *Characteristics*

Since the distinction between the malarial mosquitoes (tribe ANOPHELINI) on the one hand and other mosquitoes, particularly those belonging to the tribe CULICINI, on the other is perhaps the most important in the whole field of Medical Entomology, it is worth while to discuss these differences in some detail. There are a number of characters which may be used, but most of them are not infallible in every case, although true enough in general.

1. THE ADULT STAGE

Resting attitude. In most cases, Anopheline mosquitoes may be distinguished in life at first glance by their characteristic attitude (see Figure 228). The whole body and proboscis form a straight line at an angle to the surface on which the mosquito rests. The resting attitudes of other mosquitoes are different in different genera, but in general the Culicine mosquitoes rest with the proboscis not in line with the abdomen and the body roughly parallel to the substratum.

However, not all Anophelines have the characteristic Anopheline attitude. In the southern United States it will be noticed that the resting attitude of *A. quadrimaculatus* is intermediate between the typically Anopheline pose of *A. crucians* or *A. punctipennis* and that of a Culicine. In India one of the worst malaria-carriers has been given the name of *A. culicifacies* because of its *Culex*-like resting attitude. In South America there are two rare Anophelines, one of which, *Chagasia fajardoi,* has a "hump-backed" resting attitude like that of the Culicine genus *Mansonia,* while the other, *Anopheles nimbus,* is said to rest in the same peculiar attitude as the members of the tribe SABETHINI.

Wing spotting. It is often said that the wings of Anopheline mosquitoes are spotted, while those of other mosquitoes are unspotted. This is the rule, but there are numerous exceptions on both sides. The most primitive Anophelines have absolutely unspotted wings.

Others, like *A. quadrimaculatus,* have all the wing-scales dark colored, but at certain places on the wing the scales are more crowded than at others, giving the impression of four indistinct dark spots

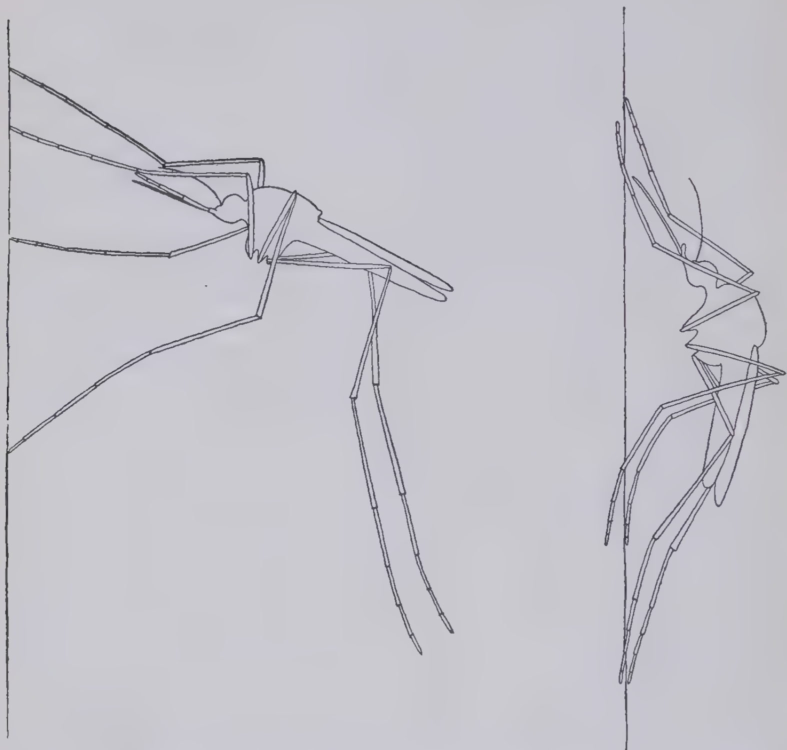


FIG. 228.—Diagrammatic representation of the typical resting attitudes of adult females of *Anopheles* (left) and *Culex* (right). (Original. Root)

when looked at with the naked eye or a hand lens. In the majority of Anophelines, however, the wings show very definite dark and light spots, due to the fact that the scales along the wing veins are dark-colored in some areas and white or cream-colored in others.

In most Culicine mosquitoes the wing-scales are all dark. But a good many species have the veins clothed with a mixture of dark and light scales and in a few forms, such as the species of the genus *Lutzia* and the species of *Culex* related to *C. mimeticus,* there are alternating areas of dark and light scales just as in the typical

Anophelines. In many species of *Culicella,* also, the wings present indistinct dark spots not unlike those of *A. quadrimaculatus.*

Form of scutellum. In most Anophelines the posterior margin of the scutellum is evenly rounded and has a regular row of bristles. In most other mosquitoes the scutellum is definitely tri-lobed posteriorly, with a clump of bristles on each of the three lobes. It must be noted, however, that the rare Anophelines of the genus *Chagasia* have the scutellum tri-lobed, and that the species of *Megarhinus* have the scutellum evenly rounded, as in *Anopheles.*

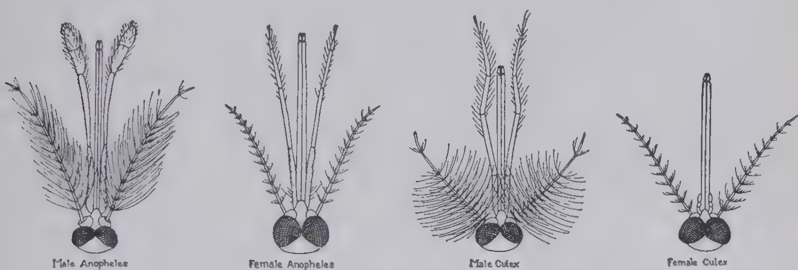


FIG. 229.—Heads of male and female adults of *Anopheles* and *Culex.* (Original. Root)

The form of the palpi. The form of the palpi is the best character for differentiating Anopheline mosquitoes from the others, but it has the disadvantage that the palpi are different in the two sexes of the same species (compare Figure 229). Male mosquitoes, of course, may be readily distinguished from females in nearly every case by their bushy, long-haired antennæ, and by the presence of the hypopygial structures at the tip of the abdomen. Most male mosquitoes have the palpi longer than the proboscis, although a few aberrant species in many different genera have short male palpi. In male *Anopheles* the last two joints of the palpi are broad and flat, giving the palpi a clubbed appearance, while male Culicines have the last two joints of the palpi tubular, like the other joints, so that the palpi are slender throughout. It should be noted, however, that in some Culicine genera, *Culicella* for example, the last two joints of the male palpi may be slightly greater in diameter than the other joints, producing a very slightly clubbed appearance. The male palpi of the peculiar Anopheline genus *Chagasia* are like those of *Culicella.*

In the females, the distinction is more obvious. All female Anophelines have palpi which are more than half as long as the proboscis, and usually they almost equal it in length. In the female Culicines, the palpi are almost always decidedly less than half as

long as the proboscis. The only exceptions are the species of *Megarhinus,* which can be readily differentiated from Anophelines by other characters.

2. THE EGG STAGE

Anophelines drop their eggs singly on to the surface of the water and although the eggs of different species vary a good deal in detail, they are almost always boat-shaped, pointed at both ends, with flat dorsal surface and convex ventral surface, and they practically always have lateral air-chambers or "floats," which aid in keeping them at the surface (see Figure 230).

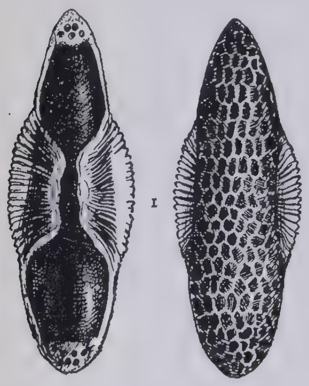


FIG. 230.—Egg of *Anopheles quadrimaculatus* in dorsal (left) and ventral (right) views. (After Howard)

Culicine mosquitoes show a good deal of variation in the way in which they lay their eggs and in their shape. In general, Culicine mosquitoes which breed in permanent bodies of water deposit "rafts" or clumps of several hundred eggs on the water surface (examples, *Culex, Uranotænia*). Those Culicine mosquitoes which breed in temporary pools (*Aëdes, Psorophora*) or in water held by plants (*Megarhinus,* SABETHINI) lay their eggs singly, usually in places which are dry at the time but will later be covered with water. Among the mosquitoes which have become domestic in their habits both of these methods of oviposition may be observed. The domestic species of *Culex* (*C. pipiens* and *C. quinquefasciatus*) lay large egg-rafts on the surface of the water. The yellow-fever mosquito (*Aëdes ægypti*) on the other hand, lays its eggs singly, sometimes on the surface of the water, but more often on the side of the container, just above the water's edge.

The eggs of Culicine mosquitoes are of various shapes, but usually are ellipsoidal or elongate-conical, and without any definite "floats."

3. THE LARVAL STAGE

Attitude at surface of water (Figure 231). Anopheline larvæ are usually readily recognizable in life by the fact that when they come to the surface for air they lie horizontally, just below the surface

film and touching the surface at several different places. Culicine larvæ usually hang vertically or obliquely when at the surface, touching the surface film only with the tip of the air-tube. The larvæ of some species of the Culicine genus *Uranotænia* have short air-tubes and hang horizontally in the water. This attitude, coupled with the fact that the heads of these larvæ have the same shape as those of Anopheline larvæ, may lead to their being mistaken for small larvæ of *Anopheles,* but on a closer examination the presence of a well-developed air-tube will correct the mistake at once. The larvæ of certain *Chaoborinæ* (especially *Eucorethra*) also resemble *Anopheles* larvæ to a certain extent.

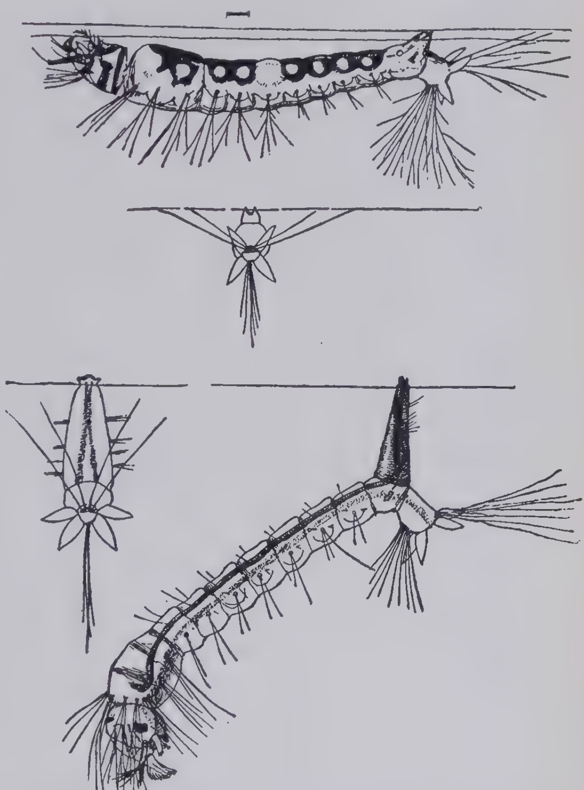


FIG. 231.—Resting attitudes of larvæ of *Anopheles* (above) and *Culex* (below). (After Howard)

Development of air-tube. Culicine larvæ always have a well-developed air-tube on the dorsum of the eighth abdominal segment. In Anopheline larvæ the air-tube is reduced to such a rudiment that for practical purposes it may be said to be absent. It should be noted that in Anopheline larvæ the two spiracular openings on the dorsum of the eighth abdominal segment are surrounded by five flap-like structures, the posterior pair of flaps being larger than the others and more or less fused together. These flaps tend to close together when the larva leaves

the surface, retaining a bubble of air above the spiracles, so that no water can enter the tracheal system. They do not correspond to the air-tube of Culicine larvæ, but to five little flaps at the tip of the air-tube, which open out, star-like, when the tip of the air-tube reaches the surface.

The shape of the head, decidedly longer than it is wide, will also serve to differentiate *Anopheles* larvæ from those of all Culicines except *Uranotænia*. The presence of palmate hairs on thorax and abdomen (see page 494) is also a characteristic of most Anopheline larvæ.

4. THE PUPAL STAGE (Figure 232)

The breathing trumpets. Anopheline pupæ can usually be recognized on microscopic examination by the form of the breathing-

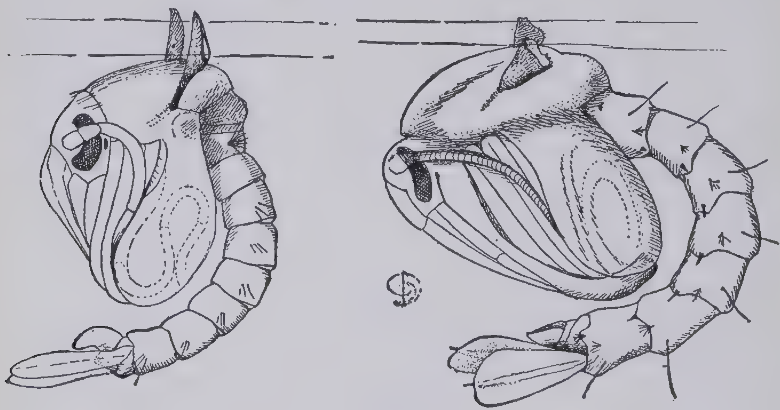


FIG. 232.—Pupæ of *Anopheles* (right) and *Culex* (left). (After Howard)

trumpets, which are short and broad with a large terminal opening which is continued by a split down the front. In pupæ of *Culex* the breathing-trumpets are long and tubular, with a small terminal opening. In other Culicine genera, such as *Aëdes*, the pupal breathing-trumpets may be short and conical, but usually do not have a split down the front nor such a large terminal opening as in *Anopheles*.

Paddles at tip of abdomen. A more certain character, but one more difficult to see, is furnished by the fact that in *Anopheles* pupæ the paddles at the tip of the abdomen have a small hair on the

surface of the paddle near its tip, in addition to a larger terminal hair. Culicine pupæ usually have a large terminal hair on the paddle, but never show the small accessory hair.

II. *Classification of Anophelini*

The tribe ANOPHELINI includes the two small and unimportant genera *Chagasia* (three species in tropical America) and *Bironella*

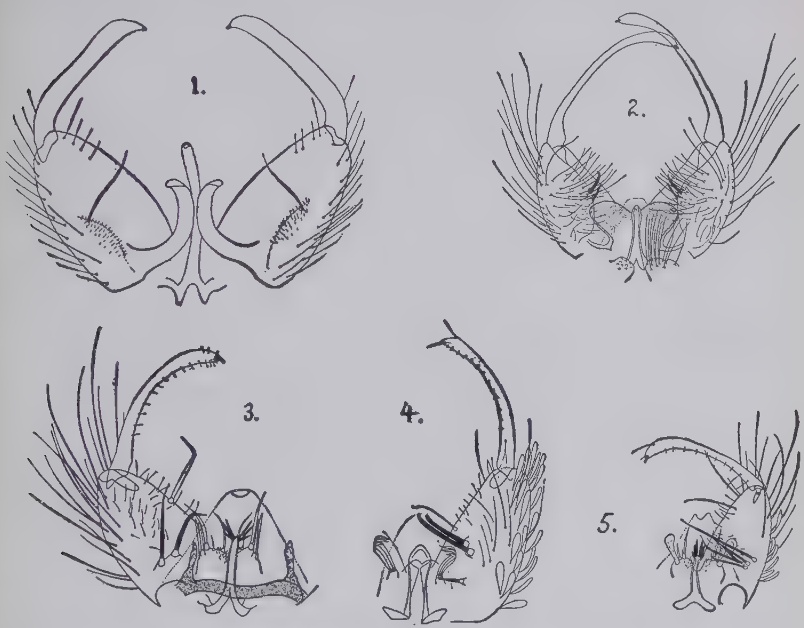


FIG. 233.—Male hypopygia of the genera and subgenera of Anopheline mosquitoes. 1, *Bironella*; 2, *Chagasia*; 3, *Anopheles* (*Anopheles*); 4. *Anopheles* (*Nyssorhynchus*); 5, *Anopheles* (*Myzomyia*). (Original. Root)

(one species in Papua) and the large genus *Anopheles*, which is further subdivided into three subgenera, *Anopheles, Nyssorhynchus* and *Myzomyia*. The subgenera may be still further subdivided into groups of species. The division into genera and subgenera is based primarily upon the structure of the male hypopygium, particularly on the structures present at the base of the *side-piece*, or basal joint of the clasping appendages. These differences may be briefly summarized as follows (compare Figure 233).

1. Inner side of side-piece with a lobe bearing 2 or more spines	*Chagasia*
2. Ventral surface of side-piece with a massive spur arising near its base...	*Bironella*
3. Ventral surface of side-piece with 1 to 6 strong spines (*parabasal spines*) near its base	*Anopheles*
3a. Two (rarely one or three) parabasal spines present...........	subgenus *Anopheles*
3b. One parabasal spine present and also two *accessory spines* arising on the ventral surface of the side-piece at about the middle of its length	subgenus *Nyssorhynchus*
3c. A clump of from four to six parabasal spines present	subgenus *Myzomyia*

III. *Geographical Distribution of Anopheles*

Some species of the genus *Anopheles* will be found in almost every region of the globe. Certain subgenera and groups, however, are more or less restricted to certain regions. The subgenus *Anopheles* includes: (a) a few rare and primitive tropical species; (b) two groups of species (Anopheles group and Patagiamyia group) which are particularly characteristic of the north temperate region, although some species of these groups are found in the tropics; (c) two highly specialized groups of tropical species one of which (Myzorhynchus group) is found only in the Old World, the other (Arribalzagaia group) only in the American tropics. The subgenus *Nyssorhynchus* is confined to the tropical and subtropical regions of the New World, the subgenus *Myzomyia* to the corresponding parts of the Old World.

No attempt will be made in this book to deal with the Anophelines of the Old World. Students who desire to become acquainted with the Old World forms may consult the papers on them listed in the bibliography.

IV. *Identification of American Species of Anopheles*

In the identification of adult Anophelines, particularly the females, it is necessary to rely on color characters, mainly on the coloration of the wings, palpi and legs. Since all these organs owe their color to their covering of scales, it is often difficult to identify

specimens which are so old or have been so carelessly handled that many of the scales have been rubbed off. In tracing the evolution of the color patterns of *Anopheles* we find that in the more primitive species the scales on wings, legs and palpi are usually all dark in color. As we pass to more and more specialized forms we find light-scaled areas appearing, at first few in number and small, then becoming more numerous and more extensive. Usually the light-scaled areas are found in certain definite places, varying in their degree of extension but not in their location. Slight shifts of location of white areas do sometimes occur, however. Frequently it is found that two adjacent light-scaled areas have extended until they have fused together, obliterating the dark-scaled area between them. In a few groups of species there seems to have been a sort of fragmentation of the white spots, so that two, three or even four small white areas appear where most species show only one large one. This is particularly well shown in the wing-pattern of the species of the Arribalzagaia group (see Figure 236).

The areas which are most useful for identification are, on the wing, the *costa* (which term means only that part of the costa which lies along the anterior margin of the wing between the wing base and the tip of the first vein), the third vein, and the sixth vein; on the legs, the tarsal joints, especially of the hind legs; and on the palps, the two terminal joints. The key which follows is intended primarily for female specimens. Males can usually be identified by it also, except that the different form of the male palpi and the reduced scaling of the male wings make characters based on these structures less reliable than in the case of females.

The key includes all the American groups of Anopheline mosquitoes, but some of the rarer and less important species have been omitted or lumped together.

KEY FOR IDENTIFYING THE ADULT FEMALES OF THE AMERICAN ANOPHELINE MOSQUITOES

1. Wings either entirely dark-scaled or with a mixture of light and dark scales, but without definite light-scaled and dark-scaled areas 2
   Wings with definite light and dark spots produced by alternating light-scaled and dark-scaled areas 3
2. Tarsi conspicuously white-banded .... (*Chagasia*) 7
   Tarsi all dark .... (Anopheles group) 9
3. Second, fourth and sixth veins of wing entirely dark-scaled, without any light areas .... (Kerteszia group) 32
   These veins with some light-scaled areas 4

4. Sixth vein with four or more small dark spots ....(Arribalzagaia group) 17
Sixth vein with only one, two or three dark spots or areas..... 5
5. Costa of wing with light areas only at tip of first vein or at tips of first vein and subcosta ....(Patagiamyia group) 13
Costa with more than two light-scaled areas 6
6. Third vein either nearly all dark or with three distinct dark spots ....(Myzorhynchella group) 25
Third vein mainly white, with a small dark spot near each end ....(Nyssorhynchus group) 27

Genus *Chagasia*

7. Wings entirely dark-scaled ....*C. fajardoi.*
Wings with a mixture of light and dark scales................ 8
8. Last four hind tarsal joints with only one black band each ....*C. bonneæ.*
Last four hind tarsal joints each with two black bands ....*C. bathanus.*

Genus *Anopheles*
Subgenus *Anopheles*
Anopheles group

9. Hind tibia with a broad white band at its tip........*A. eiseni.*
Hind tibia all dark 10
10. Mesonotum with narrow median and lateral silvery stripes ....*A. nimbus.*
Mesonotum without such narrow silvery stripes.............. 11
11. Wings with four indistinct darker spots 12
Wings not indistinctly spotted—*A. barberi, A. walkeri* and *A. atropos.*
12. Wing fringe all dark ....*A. quadrimaculatus.*
Wing fringe coppery or yellowish at tip of the wing ....*A. maculipennis.*

Patagiamyia group

13. Hind tibia with a broad white band at its tip........*A. eiseni.*
Hind tibia without a white band 14
14. Femora and tibiæ with small yellowish spots; some of the wing scales almost circular ....*A. grabhami.*
Femora and tibiæ not mottled; wing scales all slender.......... 15
15. Costa white only at tip of first vein; sixth vein with three dark spots ....*A. crucians.*
Costa white at tips of first vein and subcosta; sixth vein with only one or two dark areas 16
16. Sixth vein with two dark areas; third vein dark, except sometimes at tip; palpi dark....................*A. punctipennis.*
Sixth vein with one dark area; third vein extensively white in middle; palpi with narrow white rings..*A. pseudopunctipennis.*

Arribalzagaia group

17. Fourth and fifth hind tarsal joints all white.....*A. annulipalpis.*
    At least fourth hind tarsal joint with some black 18
18. Fifth hind tarsal all dark; third and fourth hind tarsals all dark or with small apical light rings 19
    Fifth hind tarsal partly or entirely white; third and fourth hind tarsals with at least two white rings each 21
19. Tip of abdomen conspicuously white-scaled dorsally ....*A. peryassui.*
    Tip of abdomen not white-scaled 20
20. All light spots on wings very small; middle of third vein dark ....*A. vestitipennis.*
    Light wing-spots larger and more distinct; middle of third vein with an area of mixed light and dark scales....*A. maculipes.*
21. Fifth hind tarsal all white or yellow 22
    Fifth hind tarsal with a black ring 23
22. Hind tarsi yellow, with black spots and rings..*A. mediopunctatus.*
    Hind tarsi black with white spots and rings....*A. punctimacula.*
23. Dark area at tip of wing about the same size as the dark area between it and the large dark area just beyond the tip of the subcosta ....*A. punctimacula.*
    Dark area at tip of wing decidedly larger than the dark area between it and the large dark area just beyond the tip of the subcosta 24
24. Third vein extensively white in middle; broadest wing-scales about one-third as broad as long ....*A. pseudomaculipes.*
    Third vein with numerous small light and dark areas; broadest wing-scales nearly half as broad as long, enlarged, with rounded tips ....*A. intermedius.*
    Third vein either extensively white in middle or with many small light and dark areas; broadest wing-scales nearly half as broad as long, not enlarged, truncate at tip...*A. apicimacula.*

Subgenus *Nyssorhynchus*

Myzorhynchella group

25. Third, fourth and fifth hind tarsals all white.................. 26
    Third and fourth hind tarsals with small black rings ....*A. nigritarsis.*
26. Third vein of wing nearly all dark; tip of abdomen not white-scaled dorsally ....*A. lutzi.*
    Third vein with three dark spots; tip of abdomen conspicuously white-scaled dorsally ....*A. parvus.*

Nyssorhynchus group

27. Third, fourth and fifth hind tarsals all white 28
    Fifth hind tarsal with a black ring, third and fourth white..... 30
    Black rings on fifth hind tarsal and also on either third or fourth hind tarsals or on both—*A. rondoni, A. cuyabensis* and *A. triannulatus* ....

28. White spot on costa near humeral cross-vein smaller than the black spot just basal to it .... *A. darlingi.*
White spot on costa near humeral cross-vein larger than the black spot just basal to it 29
29. Mid tarsi with definite white rings; second hind tarsal joint often with more black than white .... *A. albitarsis.*
Mid tarsi without definite white rings; second hind tarsal joint usually with much more white than black..... *A. argyritarsis.*
30. White spot on costa near humeral cross-vein larger than the black spot just basal to it 31
White spot on costa near humeral cross-vein as small as or smaller than the black spot just basal to it...... *A. bachmanni.*
31. Next to last joint of female palpi mainly black; second hind tarsal joint usually more black than white...... *A. albimanus.*
Next to last joint of female palpi mainly white; second hind tarsal joint usually more white than black .... *A. tarsimaculatus, A. strodei.*

Kerteszia group

32. Third, fourth and fifth hind tarsals all dark....... *A. boliviensis.*
Third, fourth and fifth hind tarsals with broad, white, apical rings .... *A. bellator, A. cruzi.*

V. *Identification of Anopheles Larvæ*

It is often convenient in survey and control work to be able to identify larvæ of *Anopheles* without waiting to breed out adults. All *Anopheles* larvæ look very much alike, but there are certain differences, mainly in the form and position of various hairs, which enable us to identify many larvæ. The hairs most used for identification are the following.

Head hairs. Inner and *outer* pairs of *clypeal hairs* on the anterior margin of the head. The outer clypeal hairs lie just above the protruded mouth brushes and are sometimes hard to see in preserved larvæ. The other dorsal head hairs, whose positions and names are indicated in Figure 234, are only occasionally of value.

Thoracic Hairs. The most important of the thoracic hairs is the inner hair of the *anterior submedian thoracic group,* which includes the three hairs nearest the mid-dorsal line on each side of the anterior margin of the thorax. The middle and outer hairs of this group are practically the same in all *Anopheles* larvæ, but the inner hairs show characteristic variations in certain species.

Palmate hairs. The name *palmate hairs* is applied to paired hairs which may be present on the posterior corners of the thorax and on the first to seventh abdominal segments. When fully developed, a

palmate hair consists of a short, stout, erect stalk from the top of which a number of slender, flattened *leaflets* radiate out horizontally. The number of pairs of palmate hairs varies characteristically in certain species, but is not a very good character to use, because

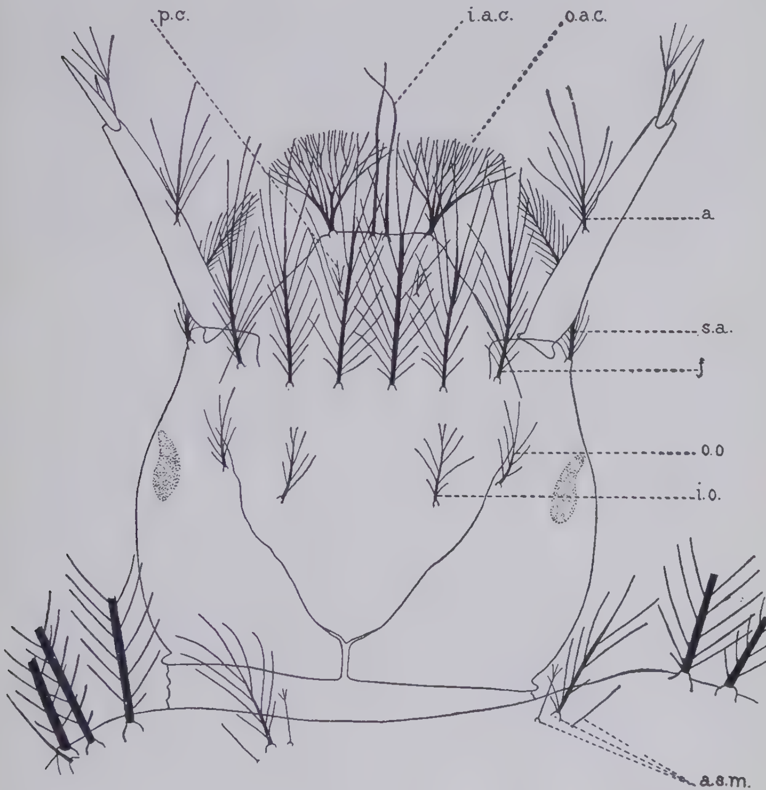


Fig. 234.—Head and anterior edge of thorax of larva of *Anopheles*. i.a.c., inner clypeal hairs; o.a.c., outer clypeal hairs; p.c., pre-antennal hairs; a., antennal hair; s.a., sub-antennal hair; f., frontal hairs; o.o., outer occipital hairs; i.o., inner occipital hairs; a.s.m., anterior submedian thoracic group of hairs. (Original. Root)

palmate hairs are readily broken off and leave no scar to mark their former position. In some species of larvæ, also, one finds hairs intermediate between ordinary hairs and the palmate type, so that it becomes difficult to decide just how many pairs of real palmate hairs are present. The shape of the individual leaflets of the palmate hairs is often characteristic of certain species or groups of species.

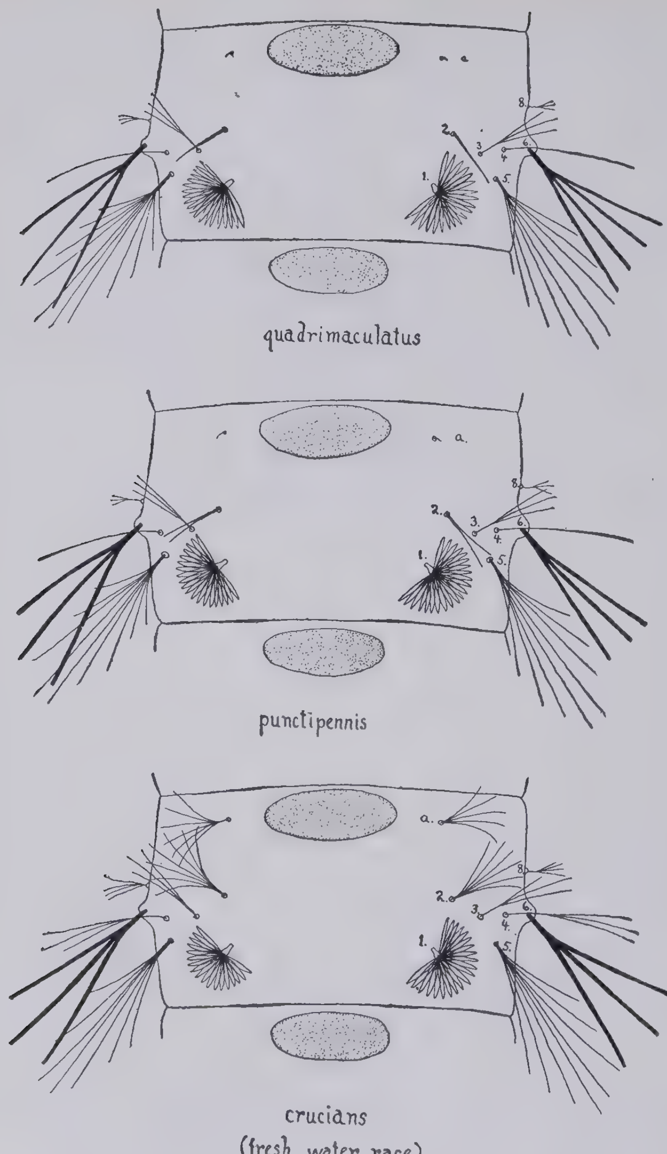


Fig. 235.—Fourth abdominal segments of the larvæ of *Anopheles quadrimaculatus, punctipennis* and the fresh-water race of *crucians*. 1, palmate hairs; 2, ante-palmate hairs; *a*, anterior hairs; 6, long lateral hairs (only the bases of these hairs are shown). (Original. Root)

Other abdominal hairs (compare Figure 235). The long *lateral abdominal hairs* are often of value. All *Anopheles* larvæ have two long, feathered lateral hairs on each side of the first and second segments of the abdomen and a single similar hair on each side of the third segment. The fourth, fifth, and, in certain groups, the sixth segment each have a pair of shorter lateral hairs, and these vary in their branching in different groups and are often useful in field identifications. The *antepalmate hairs,* the hairs nearest the mid-dorsal line just in front of the palmate hairs, on abdominal segments four and five are sometimes useful also.

The pecten. The *pecten* or comb on the eighth abdominal segment shows a characteristic arrangement of the long and short teeth in certain species, but this is a character difficult to study in living larvæ on account of the lateral position of the pecten.

The following keys are not wholly satisfactory, but it is thought that the characters used are constant enough to permit of the correct identification of the majority of larvæ encountered. In the key to the *Anopheles* larvæ of the United States, especially, the differences which have to be used, in default of better ones, are minute and subject to a certain amount of variation within the species.

KEY TO THE COMMON ANOPHELES LARVÆ OF THE UNITED STATES (COMPARE FIG. 235)

1. Clypeal hairs very small and inconspicuous; frontal hairs small and unbranched .... *A. barberi.*
   Clypeal hairs more prominent; frontal hairs long and feathered. 2
2. Both inner and outer clypeal hairs unbranched .... *A. pseudopunctipennis.*
   Inner clypeal hairs unbranched; outer clypeal hairs thickly branched, forming a flat, fan-shaped tuft 3
3. Palmate hairs absent on second abdominal segment 4
   Small palmate hairs present on second abdominal segment...... 5
4. Palmate hairs of third and seventh abdominal segments smaller than the others; antepalmate hairs of fourth and fifth abdominal segments usually single or double, sometimes triple .... *A. crucians* (brackish water race).
   Palmate hairs of third and seventh abdominal segments as large as the others; antepalmate hairs of fourth and fifth abdominal segments usually triple, but sometimes double .... *A. maculipennis.*
5. Antepalmate hairs of fourth and fifth abdominal segments forming tufts with four to nine branches; another similar pair of tufted hairs near the anterior borders of these segments, in front of the antepalmate hairs .... *A. crucians* (fresh-water race).

Antepalmate hairs of fourth and fifth abdominal segments with three or less branches; no large tufted hairs near the anterior borders of these segments 6

6. Tubercles from which inner clypeal hairs arise so close together that another similar tubercle could not be placed between them; antepalmate hairs of fourth and fifth abdominal segments usually double, sometimes single or triple....*A. punctipennis.*

Tubercles from which inner clypeal hairs arise separated at least enough so that another similar tubercle could be placed between them; antepalmate hairs of fourth and fifth abdominal segments usually single, sometimes double ....*A. quadrimaculatus.*

KEY TO THE ANOPHELINE LARVÆ OF TROPICAL AMERICA

1. Very long, feathered lateral hairs present on abdominal segments 1, 2 and 3, followed by long lateral hairs on segments 4 and 5; anterior flap of spiracular apparatus short and stout, more or less semicircular 2

Very long, feathered lateral hairs present only on abdominal segments 1 and 2, no long lateral hairs on segments 3, 4 and 5; anterior flap of spiracular apparatus long and tubular, bearing a long filament at its tip ....*Chagasia* (*C. fajardoi, C. bonneæ,* and *C. bathanus*).

2. Frontal hairs of head long and feathered 3

Frontal hairs shorter, with few or no lateral branches ....(Kerteszia group)—*A. bellator, A. cruzi.*

3. Long lateral hairs of abdominal segments 4 and 5 single and unbranched 4

Long lateral hairs of abdominal segments 4 and 5 double, triple, multiple or with lateral branches 11

4. Outer clypeal hairs thinly branched to form a flat, fan-shaped tuft with less than twenty ultimate branchlets; long lateral hairs absent on abdominal segment 6 . . . most species of the Arribalzagaia group, including *A. punctimacula, A. apicimacula, A. pseudomaculipes, A. intermedius* and *A. mediopunctatus.*

Inner and outer clypeal hairs both with a single main stem and a variable number of delicate lateral branchlets, which are sometimes difficult to see clearly; long lateral hairs present on abdominal segment 6 as well as on segments 4 and 5 (Nyssorhynchus group) 5

5. Distance between bases of the two inner clypeal hairs only about one third of the distance between the bases of the inner and outer clypeal hairs of either side 6

Distance between bases of the two inner clypeal hairs equal to or only slightly less than the distance between the bases of the inner and outer clypeal hairs of either side 7

6. Inner hair of anterior submedian thoracic group resembling a

palmate hair, i.e., with about fifteen flat, leaflet-like branches all arising at about the same level .... *A. strodei.*

Inner hair of anterior submedian thoracic group smaller, with seven or eight hair-like branches arising along a short main stem .... *A. argyritarsis.*

7. A long, erect hair present on each of the posterior flaps of the spiracular apparatus .... *A. darlingi.*

No long hairs on these organs 8

8. Inner hairs of anterior submedian thoracic group long, usually over half as long as the middle hairs, and of much the same form, with numerous hair-like branches arising along a short, thick main stem .... *A. albimanus.*

Inner hairs of anterior submedian thoracic groups short, much less than half as long as the middle hairs, and with their branches all arising at about the same level 9

9. Inner hairs of anterior submedian thoracic groups larger, with broad, usually pigmented, leaflet-like branches; the inner hairs of the two sides so close together that another similar hair could not be placed between them without overlapping .... *A. albitarsis.*

Inner hairs of anterior submedian thoracic groups smaller, their branches narrower or more transparent; those of the two sides far enough apart so that another similar hair could be placed between them without overlapping 10

10. Inner hairs of the anterior submedian thoracic groups each with about eleven, fairly broad, leaflets........ *A. tarsimaculatus.*

Inner hairs of the anterior submedian thoracic groups each with thirteen to eighteen narrower, almost hair-like leaflets .... *A. bachmanni.*

11. Outer clypeal hairs thickly branched, forming flat, fan-shaped tufts with very numerous ultimate branchlets................ 12

Outer clypeal hairs thinly branched, forming flat, fan-shaped tufts with less than twenty ultimate branchlets; lateral hairs of abdominal segments 4 and 5 double....... *A. vestitipennis.*

Outer clypeal hairs each with a single main stem, with or without delicate lateral branchlets 13

12. Inner clypeal hairs with delicate lateral branchlets near tip; lateral hairs of abdominal segments 4 and 5 double...... *A. grabhami.*

Inner clypeal hairs without any lateral branchlets; lateral hairs of abdominal segments 4 and 5 split into from three to five branches .... *A. crucians.*

13. Inner and outer clypeal hairs with a main stem bearing a number of delicate lateral branchlets; lateral hairs of abdominal segments 4 and 5 split into four or five branches.... *A parvus.*

Inner and outer clypeal hairs single, without any lateral branchlets 14

14. Inner clypeal hairs close together; lateral hairs of abdominal segments 4 and 5 double.......................... *A. eiseni.*

Inner clypeal hairs well separated; lateral hairs of abdominal segments 4 and 5 with a single main stem and a number of well-developed lateral branches .... *A. pseudopunctipennis.*

VI. *Notes on Groups and Species of American Anopheles*

I. SUBGENUS ANOPHELES

Anopheles and Patagiamyia groups. These two groups include all of the Anopheline mosquitoes of the United States and a few tropical species. In the United States *punctipennis* ranges all over the country, *quadrimaculatus* is found in most of the States east of the Rocky Mountains, but is replaced by *maculipennis* on the Pacific Coast and along the northern border, *crucians* occurs mainly in the Southeastern States and *pseudopunctipennis* is found in the southwest from California to Texas. This last species has the widest range of any in these groups, since it occurs all through Central America, on the west coast of South America, and is widely distributed in the northwestern part of Argentina, where it is said to be the most important vector of malaria. In other parts of its range it is not considered to be an important carrier. In the United States, malaria is carried mainly by *quadrimaculatus* in the Southern States and by *maculipennis* on the Pacific Coast. Individuals of *punctipennis* and *crucians* have been found in nature infected with malaria parasites, but they are not considered to be as dangerous vectors of the disease as *quadrimaculatus* and *maculipennis.*

The larvæ of the species which occur in the United States resemble each other very closely and are difficult to identify. To add to the difficulty, it has been shown that *A. crucians* exists in two races, one breeding in the salt-marshes along the coast from New York to Texas, the other inhabiting fresh-water ponds in Georgia and Alabama. The larvæ of these two races are quite different, but no adult differences have yet been demonstrated.

Arribalzagaia group. The species of this group breed mainly in jungle pools, and none of them are considered to be dangerous carriers of malaria. Many of the species are rare, but *punctimacula* is quite abundant in Panama and other Central American countries, *apicimacula* in Venezuela and *intermedius* and *pseudomaculipes* in Brazil. The larvæ of the species of this group are all very similar and difficult to distinguish, although readily identifiable as members of the group by the form of the outer clypeal hairs. In Venezuela the author found it possible to distinguish larvæ of *punctimacula* and *apicimacula* by the pecten teeth, which showed a regular alternation of long and short teeth in *punctimacula,* while the pecten of *apicimacula* always had at least one place where two or three short teeth stood together without intervening long teeth. Although the

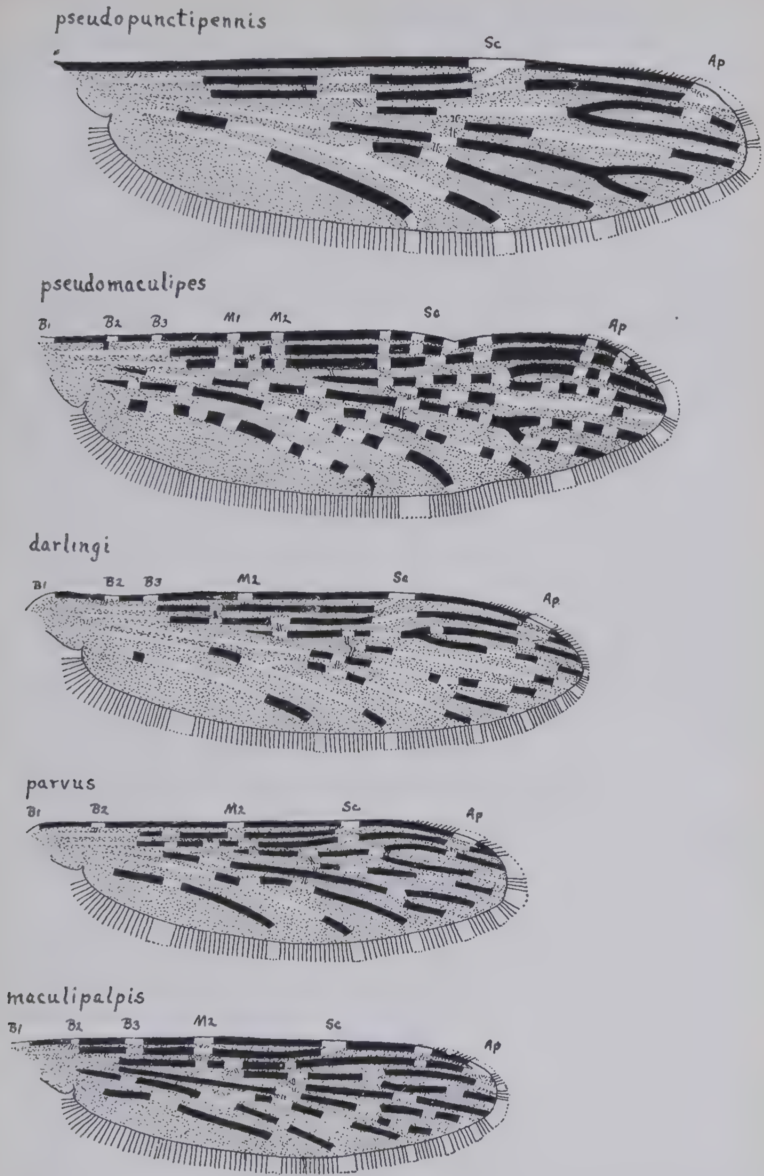


FIG. 236.—Diagrams of the wing patterns of various species of *Anopheles*: *A. pseudopunctipennis* (Patagiamyia group), *A. pseudomaculipes* (Arribalzagaia group), *A. darlingi* (Nyssorhynchus group), *A. parvus* (Myzorhynchella group), *A. maculipalpis* (subgenus (*Myzomyia*).

larvæ are difficult to differentiate, the pupæ of the species I have studied show characteristic differences in the form of their breathing-trumpets, which is not usually the case in other groups.

2. SUBGENUS NYSSORHYNCHUS

Myzorhynchella group. Includes three species from the interior of Brazil, which are evidently not important vectors of malaria.

Nyssorhynchus group. This group of "white-hind-footed" species includes the most abundant Anophelines and the most important malaria-carriers of Tropical America. Many closely-related species or varieties are known in this group and there are very likely others which have not yet been described. We also need further information on the relations of the different forms to the transmission of malaria. The information at present available indicates that *albimanus* is the most important malaria-carrier of the Caribbean littorals and that either *albitarsis* or *darlingi* or both are the most important vectors in the lowlands of Brazil. Boyd (1926) has also shown that *tarsimaculatus* is a malaria-carrier, but of less importance than the others mentioned.

The adult markings of species of this group are unusually variable, and in working out the fauna of a region which has not been carefully studied previously, it is essential to base identifications on larval and hypopygial characters, which are comparatively stable, instead of on the variable characters of the adult coloration.

Kerteszia group. The species of this group are very small Anophelines, which breed in the water held by the leaf bases of epiphytic Bromeliads; that is, plants of the pineapple family (BROMELIACEÆ) which grow on the trunks and branches of trees. They are usually rare or local in their occurrence and are probably not important vectors of malaria.

CHAPTER XXXVII

MALARIA AND MOSQUITO SURVEYS

Surveys of the prevalence of malaria and of Anopheline mosquitoes are usually made either to determine whether a control project is feasible or else before and after the application of control measures, to enable one to evaluate their efficacy. If it is intended to abate a mosquito nuisance as well as reduce malaria, the survey must be extended to include other mosquitoes also. But, in the tropics particularly, it is usually advisable to restrict control measures not only to Anopheline mosquitoes alone, but even to the few species of *Anopheles* which can be proved to be the most important malaria-vectors of the region. Unless this is done, the project will often prove too costly for adoption.

In order to combat malaria intelligently in any locality it is absolutely necessary to do a certain amount of survey work in that locality. It is often unsafe to accept information about the potentialities of a species of *Anopheles* as a vector of malaria, or control measures which have proved successful in other regions, without making a survey first to be sure that these data are really applicable to your own locality.

The survey should give information on the following points, which will be treated in turn:

I. The prevalence of malaria.
II. The species of *Anopheles* present, their relative abundance, and their breeding-places.
III. Which species of *Anopheles* are the malaria-vectors of sanitary importance.

I. *The Prevalence of Malaria*

We have as yet no entirely satisfactory method for determining the proportion of a given population which are actually infected with malaria parasites. There are, however, several methods which will give a measure of the prevalence of malaria which is satisfactory for comparative use, provided that the two surveys to be compared used

the same methods and technic. Since one is usually more interested in comparing the incidence of malaria in two different regions, or in the same area before and after control, than in the actual number of people infected with the disease, these methods are all reasonably satisfactory for practical purposes.

1. CASE INDEX

In a civilized community, the prevalence of malaria may be measured by persuading the physicians to report all their malaria cases during stated periods of time. We must remember, however, that not only may there be errors in diagnosis, but also that in a malarious region the majority of cases of malaria are never seen by a physician, being treated at home by "chill-tonics" and the like.

2. HISTORY INDEX

Among intelligent people, the prevalence of malaria may be approximated by a series of house-to-house visits by an inspector who finds out how many of the occupants of each house have suffered from "chills and fever" during the past year, for example. Here one is sure that no one in the population or the sample of the population selected for study has been overlooked, but errors in diagnosis or interpretation are much greater than in dealing with trained physicians.

3. PARASITE INDEX

This is obtained by making blood smears from the entire population or a sample thereof and examining them for the malaria parasites. It is advisable to record both the percentage of individuals infected with each of the three species of parasites and the percentage of *gamete carriers,* individuals who have more than one gamete to each 500 leucocytes, and are thus presumably capable of infecting mosquitoes. In examining blood smears for survey purposes it is essential to use the same technic throughout, if the surveys are to be comparable. Two surveys of the same individuals and made at the same time would yield widely divergent results if thin smears were used in one and thick smears in the other, or even if the smears were examined for ten minutes before being called negative in one and for five minutes in the other. Microscopists should be given intensive training before the real survey is begun, in order to minimize as far as possible errors due to their progressively increasing skill in detecting the parasites.

4. SPLEEN INDEX

Obtained by examining a sample of the population by palpation to determine the percentage of individuals with enlarged spleens. It is usually desirable to examine samples of both adults and of children under ten years in each locality, so as to distinguish between endemic and epidemic malaria. In comparing spleen indices obtained in two different surveys it must be remembered that the number of slightly enlarged (barely palpable) spleens found will vary decidedly according to the position in which the examination is made (standing or lying), whether clothing is loosened or not, and according to the skill of the examiner. It must also be kept in mind that diseases other than malaria, notably kala-azar, produce enlargement of the spleen.

It is frequently advisable to combine two of these indices. In the southern United States a combined history and parasite index has sometimes been used, by taking blood-smears only from those individuals who gave a negative history. In the tropics it is usual to palpate the spleen at the same time that the blood-smear is obtained for the parasite index. Such combined indices will almost invariably give higher percentages of infection than either index alone.

II. *Anopheline Surveys*

Although the work of surveying the Anopheline fauna of the locality and of determining the dangerous carriers among them should be carried on together, it is convenient to take up these two questions separately.

In order to be sure of obtaining all the species of *Anopheles* found in a given region, both adults and larvæ should be collected, for it sometimes happens that a species is easy to obtain in one of these stages but difficult to find in the other.

Adult mosquitoes are usually caught with a chloroform tube, made by placing rubber bands or a piece of a rubber stopper in the bottom of a large test-tube, pouring over them all the chloroform they will absorb and covering them first with cotton and then with a perforated disc of cardboard or cork. Such a tube should be kept tightly corked when not in use. The adults may be preserved for study by transfixing them with slender pins (the tiny pins called "minuten-nadeln" are often used) and pinning them into a cork-lined insect box or by placing them in pill-boxes with a thin layer of cotton to prevent their shaking about. In either case the specimens need to be fumi-

gated frequently with carbon disulphide to prevent their being eaten up by museum pests. The specimens should be handled as little as possible and only with a pair of fine-pointed forceps.

Adult Anophelines should be collected in their daytime resting places, both in houses and stables and in hollow trees or under bridges and culverts near their breeding-places. It is especially important to capture adults in sleeping-rooms, for usually the most dangerous carriers are to be found here. It is also advisable to make catches of adults with animal bait, collecting them at dusk as they come to bite a tame horse or cow. Regular timed catches of this sort are particularly valuable in following the reduction in numbers of adults during control work.

In searching for Anopheline larvæ one needs a dipper (preferably white-enamel lined and with a hollow handle in which a wooden staff may be inserted), a large-mouthed pipette or medicine dropper for picking out larvæ and pupæ from the dipper, and bottles for carrying them back to the laboratory. In the laboratory there should be a series of small bowls or pans for the larvæ and plenty of gauze-covered lantern chimneys, bottles or test-tubes for breeding out adults from the pupæ.

In dipping for Anopheline larvæ, which are usually at the surface of the water, the dipper should skim the surface or be lowered gently into the water so that the surface water will run into it. Experience will soon show that larvæ are usually obtained in the greatest numbers by dipping where the aquatic vegetation is thick enough to shelter them from fish.

Larvæ should be sought in every possible breeding-place, including not only ponds, streams and marshes but also puddles, hoof-prints, barrels, tanks, tree-holes and water-holding plants. Careful records of just what specimens are bred from each breeding-place should, of course, be kept. In a systematic survey it is best to make a detailed map of the territory surveyed, marking the location of every breeding-place discovered, and designating each breeding-place by a number. Collections of larvæ and pupæ can be labeled with the number of the breeding-place where they were secured and with the date of collection or a serial number or letter from which the date may be found by reference to one's notes.

It is usually easy to breed out adults if only large larvæ and pupæ are collected. Small larvæ are more difficult to rear because they must be supplied with food and the water changed regularly before it becomes at all foul. For food one may use very small amounts of

dried and powdered insect tissue, yeast or dried blood-serum, by sprinkling them on the surface of the water in the breeding dishes. If a good culture of unicellular algæ or protozoa can be maintained in the laboratory it makes excellent food for rearing larvæ.

III. *Anopheline Breeding-Places*

If we were to glance over the Anopheline fauna of the whole world, we should find that some species of *Anopheles,* somewhere, will breed in almost any conceivable sort of water-collection. Some species have a wide range of habitats, while others are very restricted in their breeding.

The great majority of species probably prefer the comparatively pure, standing, fresh water of pools, ponds, marshes and swamps, but there are many exceptions to this rule. Some few species, like *A. subpictus* of India, are said to prefer polluted water. *Chagasia fajardoi* in Brazil and *A. maculatus* and its allies in the Orient breed in swift-flowing streams, and larvæ of many different species may be found in the vegetation along the edges of flowing streams and ditches. Some species prefer brackish to fresh water. Some require sunlight, others shade. Several Anophelines breed only in water-holding plants. Thus *A. barberi* and its relatives breed in the water held by rot holes in trees, the Kerteszia group of tropical America in the leaf bases of Bromeliads and the Oriental *A. asiaticus* in cut bamboo stems.

In the eastern United States, *A. quadrimaculatus* is primarily a pond breeder, although it may be found in other places. *A. crucians* also is found mainly in ponds, one race in the pools in coastal salt-marshes, the other in the fresh-water ponds of the interior. *A. punctipennis* frequently breeds in ponds and marshes, but also breeds abundantly in springs, streams and ditches. *A. barberi* is found only in tree holes. Two other rarer species occur in this area, *A. atropos* breeding in brackish water along the Gulf Coast and *A. walkeri* found locally all over the area, usually breeding in the flood-pools near rivers.

IV. *Determination of the Dangerous Vectors of the Locality*

There are three ways in which one may get an idea as to which species of *Anopheles* are the really important vectors of malaria in any locality.

1. EPIDEMIOLOGICAL "INDEX"

Sometimes it is possible to correlate the occurrence of severe malaria with the presence of a particular species of *Anopheles*. If, for example, surveys are made of two localities, one with severe malaria, the other with little or none, and it is found that the only difference between the Anopheline faunas of the two localities is that a certain species of *Anopheles* is abundant in the malarious region and rare or absent from the non-malarious region, it creates a strong presumption that this species is the vector of the disease. Such clear-cut cases are not often encountered, however, so that it is usually necessary to resort to more laborious measures.

2. EXPERIMENTAL INDEX OF INFECTION

If hospital facilities are available, so that several patients who are good gamete carriers (see page 504) can be kept at hand, information regarding the potentialities of the different species of *Anopheles* as malaria-vectors may be obtained by breeding out large numbers of female *Anopheles* from pupæ, allowing them to feed on the gamete carriers, and dissecting them from four to ten days later to see if the malaria parasites have developed in them. Under these circumstances it is not unusual to find from 25 per cent to 50 per cent of the specimens of a good vector infected, so that it is not necessary to dissect very large numbers of mosquitoes. One is never quite certain, however, that laboratory conditions and natural conditions are the same. It is conceivable that a species of *Anopheles* which is potentially a dangerous vector may in nature have habits which make it feed on human beings so seldom that it is not, in fact, of any sanitary importance.

3. NATURAL INDEX OF INFECTION

This is obtained by collecting adult female Anophelines, particularly in houses, and dissecting them in search of the malaria parasites after they have been kept alive in the laboratory for a few days to give them time to digest their latest blood-meal. This is the most reliable of the three methods, but since the natural rate of infection may be as low as 1 per cent and is usually below 10 per cent, even in a good vector, large numbers of mosquitoes must be dissected before accurate conclusions can be reached. In comparing natural infection rates secured in different places or at different

times it must be remembered, also, that the percentage of the individuals of any species of Anopheles which are infected with malaria parasites must obviously depend on many other factors besides its capacity to act as a host for these parasites. Some of these factors are, in all probability, the percentage of good gamete carriers in the human population, the comparative abundance of human and animal sources of blood, and the climatic conditions of temperature, humidity and so on.

V. *Dissection of Anopheline Mosquitoes*

The so-called "dissection" of Anopheline mosquitoes is not so difficult as it sounds. A dissecting lens or binocular microscope should be used for the actual dissection and the high power (4 mm. objective, No. 10 ocular) of the compound microscope is needed in the examination for malaria parasites.

As has been described in Section I of this book, the malaria parasites may be found in two parts of the mosquito, as oöcysts in the stomach-wall or as sporozoites in the cells of the salivary glands. In dissecting mosquitoes we aim only at extracting these two organs for examination. The only tools needed are two fine needles mounted in wooden handles. It is convenient to have one of these needles ground to a sharp cutting edge on one side and left blunt or rounded on the other.

The legs and wings of the mosquito are cut off near their bases and the body placed on a clean glass slide with the tip of the abdomen extending into a drop of normal salt solution. The stomach can usually be drawn out by holding the thorax in place with one needle and pulling gently on the last segments of the abdomen with the other. If the alimentary canal should break behind instead of in front of the stomach, the abdominal wall can be detached at its base and pulled away, exposing the stomach. The intestine and Malpighian tubules should be cut off and removed before placing a cover-slip on the stomach to flatten it out for examination. If mature oöcysts are present, they can often be seen, projecting from the stomach wall, under the binocular, but younger oöcysts can only be found by careful search with the high power of the compound microscope.

The salivary glands are in the thorax, near the fore coxæ. To secure them the mosquito is turned around, with its head projecting into a drop of normal saline. Often the salivary glands may be drawn out, attached to the head by their ducts, by holding the thorax in

place with one needle and pulling gently on the head with another until it breaks away from the thorax. If this fails, press gently on the thorax with the blunt edge of the needle, being careful not to break the integument, until a little mass of tissue is forced out through the neck opening. Cut off this little mass of tissue and tease it apart until you can see the glands clearly.

For dissection, freshly killed mosquitoes must be used. Even an hour after death they are not entirely satisfactory to work with.

CHAPTER XXXVIII

MALARIA CONTROL

Although some of them do not belong strictly to the entomological section of this book, we may, for the sake of completeness, briefly notice the various methods of dealing with malaria.

I. *Measures of Defense, which are Intended only for the Protection of Individuals or Limited Groups of People Living in a Malarious Region*

1. QUININE PROPHYLAXIS

Recent studies have cast doubt on the view that the sporozoites inoculated by the bite of an infected mosquito can be killed before they have time to develop by taking daily doses of quinine. However, the daily use of quinine while in a malarious region will often prevent the appearance of symptoms, even though infection has taken place, which makes it a valuable practice. Daily doses of from 5 to 10 grains of quinine sulphate are recommended.

2. SEGREGATION

Since the natives and especially the native children are the main reservoirs from which mosquitoes become infected in the tropics, it is possible to protect a small foreign colony by locating it far enough away from the native habitations so that few or no female *Anopheles* will fly from one to the other.

3. SCREENING

While the screening of houses or sleeping-rooms and the use of bed-nets or head-veils by individuals are more often prompted by a desire to be free from the annoyance of mosquito bites than undertaken as an antimalarial measure, they are nevertheless valuable for the latter purpose. As an antimalarial measure, screening both prevents mosquitoes from biting gamete carriers and thus becoming

infected and protects healthy individuals from the bites of infected mosquitoes. Ordinary fly-screens are of no value against mosquitoes. The mesh must be at least sixteen to the inch (eighteen is better) and metal screening should be of copper or a resistant alloy, particularly in the tropics or near the seacoast. The screening should be thorough, and in barracks or houses whose doors are frequently opened at dusk there should be a supplementary routine of capturing or killing any mosquitoes which get inside.

Under this same heading should be mentioned the possibility of painting the walls of unscreened houses with substances which repel mosquitoes. Creosote has been used for this purpose.

II. *Measures of Attack, which Aim at the Reduction or Eradication of Malaria in a Given Region*

1. STERILIZATION OF HUMAN CARRIERS OF THE MALARIA PARASITES

If a drug was known which would surely kill all the malaria parasites in a human being when given in a single dose or a few repeated doses, it is probable that the sterilization of human carriers would be the best and cheapest way of controlling malaria. As matters actually stand, however, the course of treatment usually adopted for this purpose requires the taking of 10 or 15 grains of quinine sulphate daily for a period of two months. The sole reliance on this method in an antimalarial campaign thus requires such an army of inspectors or nurses to make "follow-up" visits for the purpose of making certain that the infected individuals are continuing to take their quinine regularly, that it becomes an extremely expensive control method, in most cases.

2. MOSQUITO REDUCTION

The method of controlling malaria by reducing the numbers of the mosquito vectors to a point where they can no longer carry the disease effectively is the best-known and most widely used malaria-control measure. As has already been suggested, it is advisable to find out what species of *Anopheles* are the really important vectors, and restrict control-measures to these species, so far as is possible. This keeps down the cost of the work, which is the real problem nowadays. The work of Gorgas in Panama showed that malaria could be controlled under the most unfavorable conditions, provided expense was a secondary matter. The goal we must aim for now is

to devise methods which will enable us to control malaria in any community *at a cost which that community is able and willing to bear.*

Killing adult mosquitoes. No satisfactory way of attacking the adult stage has yet been devised. Hand-catching has been used to a certain extent in the Canal Zone as a supplementary measure. Traps of various sorts have been tried out, but neither a satisfactory model for a trap nor an efficient bait has yet been developed. Fumigation with sulphur dioxide, fumes of insect-powder or hydrocyanic acid gas has occasionally proved useful, particularly when resting or hibernating adults were found in large numbers in houses. Various insects, animals and birds, including dragon-flies, swallows, swifts, goatsuckers and bats, are known to feed on mosquitoes to some extent, but no one has found a way to increase their numbers to a point where the mosquitoes will be decidedly reduced.

Killing larval mosquitoes. The larval stages, which are always found in water, offer the easiest point of attack if we want to actually kill mosquitoes. Use is made both of poisons of various sorts and of natural enemies. Poisonous chemicals used to kill mosquito larvæ are often called "larvicides" and are of two types, *contact poisons* which kill when they touch the larva, and *stomach poisons* which have no effect until they are eaten by the larva.

Oiling. The petroleum oils are the most generally used contact larvicides. Freeborn and Atsatt (1918) have shown that an oil film does not kill mosquito larvæ by plugging the tracheæ and thus asphyxiating them, as most people suppose, but is actually toxic to them. A volatile oil like gasoline is more toxic than a heavier oil like kerosene or crude oil. However, the heavier oils are more generally used because they are cheaper and form a more permanent film. Fuel oil and crude oil are so heavy that they must be either heated or mixed with a certain amount of kerosene before they can be used in a sprayer. The addition of a small percentage of castor oil or pine oil will make the resulting film spread farther and more rapidly.

The most generally useful implement for applying oil is the knapsack sprayer. Oil-soaked sawdust is useful for broadcasting over water with thick vegetation, such as rice-fields, and for treating water-soaked pastures full of hoof prints. Mops dipped in oil may also be used in the last-named type of breeding-place. Oil-soaked sawdust or cotton-waste may be packed into bags or cages and anchored in streams or ponds. A great variety of "drip-cans" and "bubblers" have also been devised to keep up a continual application of oil to streams or ponds.

A single application of oil will kill all mosquito eggs, larvæ and pupæ in the water at that time, and prevent egg-laying until the film begins to break up. Another application must be made in time to kill the larvæ which hatch from the first eggs laid before they reach the adult stage. In practice it has been found advisable to repeat the oiling once a week throughout the breeding season. In the interest of economy, it is best to have an inspector go over the area each week and mark for oiling only those breeding-places where large larvæ or pupæ are actually present. Oil applied to breeding-places where there are no larvæ is absolutely wasted.

Other contact larvicides. Many other contact poisons besides oil have been used against mosquito larvæ. The best known mixture is the "Panama larvicide," a soap of caustic soda and resin containing crude phenol. This mixes with the water and kills larvæ and the algæ on which they feed in dilutions up to 1-10,000. It also kills fish and should not be used in water which may be used for drinking or cooking. Creosote, nitre cake and borax have also been used for poisoning water in abandoned cisterns, fire buckets and barrels.

Paris Green. The stomach poison most generally used against *Anopheles* larvæ is Paris green. This arsenical is in the form of a very fine powder, relatively insoluble in water. The small particles remain floating on the water, where they are eaten by the surface-feeding larvæ of *Anopheles* but not by the larvæ of Culicine mosquitoes, which feed below the surface. Since the Paris green must be eaten to have any effect, it does not kill eggs or pupæ, nor does it prevent oviposition. Paris green is so deadly to *Anopheles* larvæ that it should be diluted with some fine inert powder, such as ordinary road dust, before applying it. One part of Paris green to 100 parts of the inert dust is enough. This mixture may be applied by tossing handfuls of it into the air to form dust-clouds which will drift with the wind over the pond or marsh to be treated or by means of "dust-guns" or "blowers." It is preferable to make the application on a sunny day with gentle wind, after the dew has disappeared from the vegetation. It must be repeated every week or ten days.

Paris green is extremely effective in killing *Anopheles* larvæ, even when the water is thickly covered with aquatic vegetation. It is used in such small amounts that there is no danger of poisoning fish or animals which may drink the water on which it has been used. Unless the person who applies it is very careless about inhaling the dust or not cleansing his hands after handling the Paris green mixture, he runs very little risk of arsenical poisoning.

Roubaud (1920, 1926) has shown that powdered paraform,

trioxymethylene and calcium arsenate may be used in the same way as Paris green. He also points out that these chemicals, particularly trioxymethylene, may be made to sink below the surface by mechanical agitation of the water and are then effective against Culicine larvæ.

Natural enemies of mosquito larvæ. Although there are many aquatic insects and insect larvæ which feed more or less on mosquito larvæ, these are not of practical value in control work. Use may often be made, however, of small, surface-feeding fish. The best types for use in control work are the viviparous top-minnows, like *Gambusia affinis* of the Southern United States. Besides being surface-feeders, which eat mosquito larvæ whenever they can get at them, this particular type of fish has the additional advantage of giving birth to living young, so that they are able to breed anywhere, even in tanks and wells.

In nature it often happens that we find top-minnows and *Anopheles* larvæ very abundant in the same body of water. Study of such areas always shows that the existence of the larvæ is dependent on the presence of aquatic vegetation thick enough to shelter them from the fish. To obtain effective fish control, then, it is necessary either to remove the sheltering vegetation or to use such large numbers of minnows that they will be driven by hunger to penetrate into the vegetation, where they would not attempt to go if sufficient food were available elsewhere.

Many larger fish feed on the little top-minnows, so that it is necessary either to use them only in bodies of water which do not contain other fish or to make sure that there are shallow areas around the edges where the larger fish cannot follow them.

Various species of top-minnows and other small, larva-eating fish are found in many different parts of the world. Before attempting to introduce some foreign species, therefore, it is advisable to study the local fish fauna, to see if there is not some native species which could be used just as effectively.

III. *Destroying Mosquito Breeding-Places*

Since mosquito larvæ can live only in water, it is obvious that if the water is removed the mosquitoes can no longer breed there.

Surface drainage. In most cases, the easiest way to destroy a pond or marsh is to dig a ditch which will drain off the water. Drainage ditches should be as straight as possible, with gradual curves, if necessary, rather than sharp bends. The sides should slope

steeply and the bottom be narrow, and both should be kept free of vegetation or other obstructions which would impede the free flow of water and make the ditch itself a possible breeding-place. In drainage work which is intended to be permanent, it may be cheaper in the long run to give the ditches a lining of concrete or asphalt. Ditches are usually dug by hand, but in large operations ditching machines or a series of charges of dynamite may be used. If dangerous Anophelines are breeding along the edges of streams, the stream-bed must be made ditch-like so as to destroy such breeding-places.

Sub-soil drainage. Underground drains of tile or pipe have the advantage of lowering the ground water level and of doing away with all possibility of breeding in the drainage ditches. They are often used to intercept seepage outcrops and must be used to a considerable extent in regions where the principal vectors of malaria breed in rapid streams and ditches.

Vertical drainage. In limestone regions, where pervious strata of rock occur near the surface, ponds or marshes can sometimes be drained by boring a well through the impervious surface strata in the center of the area and draining all the water into this well so that it is carried off underground.

Filling. Small pools or marshes which cannot be economically drained may be filled in with earth or rock. Near large cities, rubbish, ashes and the like may be used. Care should be taken, of course, to avoid making new breeding-places in "borrow-pits" from which earth is taken.

Ponding. If confronted with a large marsh which can neither be drained nor filled in at a reasonable cost, one solution is to dig a pond in the center and concentrate all the water in it, thus reducing the surface area. Breeding in such a pond can then be controlled by the introduction of top-minnows or the use of larvicides.

Clearing and cleaning up. When a dangerous species of *Anopheles* breeds only in shaded pools, its breeding-places may be destroyed by clearing away the trees and shrubs about these pools. More often, however, it will be found that the dangerous vectors are not shade-breeders, so that clearing the ground around a jungle pool may convert an innocuous into a dangerous breeding-place.

It is also obvious that if a dangerous Anopheline should be found breeding in artificial containers or in water-holding plants these must be removed, screened or destroyed. Cleaning up artificial containers about houses will, in any case, greatly reduce the numbers of the domestic Culicines, and is often undertaken for that purpose.

IV. *General Considerations*

Area to be controlled. One of the most important questions for decision in any malaria-control campaign is as to the size of the area to which control measures are to be applied. In theory one should control a zone surrounding the area to be protected and wide enough so that the dangerous Anophelines cannot fly across it. If heavy breeding was found the zone would need to be wider than if the breeding were light. Flights of over one mile for *A. quadrimaculatus* and over two miles for *A. albimanus* have been reported, and the control of zones as wide as this is quite expensive. In practice, then, the width of the control zone surrounding the area will depend to a considerable extent on the amount of money available. Fortunately experience has shown that even partial control of Anopheline breeding may give a decided reduction in malaria, so that it is worth while to do control work even if the width of the surrounding zone must be reduced to one-half or even one-quarter of a mile.

Comparative advantages of drainage and larvicidal measures. The destruction of mosquito larvæ by the use of oil, Paris green and so on is a control measure the first cost of which is very low. But since it must be repeated many times during each breeding season, year after year, it becomes very expensive if continued long enough. The destruction of breeding-places by drainage, on the other hand, is a control measure with a high first cost but a much smaller expenditure for upkeep, which makes it much cheaper than larvicidal measures over a term of years.

If, then, one wishes to control malaria for a year or two only, little drainage should be done and oil and Paris green used freely. But, if a permanent control program is in view, drainage should be used as much as possible and larvicidal measures given a very subordinate place. If the money for a complete drainage program is not immediately available, as much new drainage as possible should be put in each year, after reserving funds for the upkeep of previously constructed drainage and for larvicidal control of all undrained breeding-places. In this way the program will ultimately be completed and control continuously maintained. It is probably needless to point out that anti-malarial drainage is an engineering problem, and should be supervised by a trained Sanitary Engineer, if possible.

"Trap breeding-places." It is not always advisable to destroy certain breeding-places, even though they could be easily abolished.

If the destruction of an easily controllable, preferred breeding-place might force the mosquitoes to breed in another potential breeding-place which could not be easily controlled but is not of importance so long as the preferred breeding-place remains available, it would be best not to destroy the first breeding-place but to leave it to act as a trap. The mosquitoes could be allowed to lay their eggs there and the resulting larvæ prevented from reaching maturity by the use of fish or larvicides. This principle is not usually of great importance in malaria-control work, but is occasionally of use, and it becomes of considerable importance in the control of the yellow-fever mosquito.

CHAPTER XXXIX

CULICINE MOSQUITOES

The name "Culicine mosquitoes" is often used to apply to all mosquitoes except the Anophelines, although, strictly speaking, it should be used only for those which belong to the tribe CULICINI. Keys have already been given (page 482) to the tribes of CULICINÆ by adult and larval characters. Three of these tribes may be dismissed very briefly, since they include no species of medical importance.

I. *Tribe Megarhinini*

Includes only a single genus, *Megarhinus*. The adults are large mosquitoes with brilliant metallic coloration. They may be differentiated from all other mosquitoes by the form of the proboscis, which is very long, curved, and tapering in both sexes. In this genus even the females are unable to bite and feed only on nectar and other plant juices. The larvæ are large, dark-colored, and feed on other mosquito larvæ. They usually breed in tree-holes, bromeliads and other collections of water held by plants, but occasionally occur in artificial containers. *M. septentrionalis* is the only species which is at all abundant in the United States.

II. *Tribe Uranotænini*

Includes only a single genus, *Uranotænia*. The adults are small mosquitoes, which almost always have lines or patches of brilliant blue scales on the dorsal or lateral surface of the thorax and sometimes on the basal portions of certain wing-veins. The larvæ of many species may easily be mistaken at first glance for small *Anopheles* larvæ, since they lie horizontally in the water and have an oval head. The short air-tube is not obvious in looking down upon the larvæ as they rest at the surface, although it is readily seen in a side view. They usually breed in permanent ponds and marshes but are also found in pitcher-plants in the Orient. *U. sapphirinus* is the only species found in the eastern United States.

III. *Tribe Sabethini*

Includes a considerable number of genera, some of which are found only in the New World, while others are peculiar to the Old World. The adults may be large or small, brilliantly metallic or dull in coloration. Some species bite man readily, others do not, but since all of them breed in collections of water held by plants they seldom are abundant enough to constitute a real pest. The larvæ and pupæ are usually whitish or yellowish in color. Most of the larvæ feed on minute organisms or fragments of dead insects, but the larvæ of some of the larger species eat other mosquito larvæ. Most of the species are tropical. The only generally distributed form in the eastern United States is *Wyeomyia smithi,* which breeds in the leaves of the pitcher-plant, *Sarracenia purpurea.*

KEYS TO THE AMERICAN GENERA OF THE TRIBE SABETHINI

By Adult Characters

1. Pronotal bristles absent 2
   Pronotal bristles present 4
2. Prealar bristles absent.......*Sabethes* (including *Sabethoides*).
   Prealar bristles present 3
3. Spiracular bristles absent ....*Limatus.*
   Spiracular bristles present—*Wyeomyia* (including *Miamyia, Prosopolepis* and *Menolepis*).
4. Clypeus with bristles ....*Joblotia.*
   Clypeus without bristles...........*Gœldia* (including *Isostomyia*).

By Larval Characters

1. Lateral comb of eighth abdominal segment absent......*Joblotia.*
   Lateral comb present 2
2. Maxilla with a single slender spine or tooth at its tip..*Sabethes.*
   Maxilla with a long and a short spine or tooth at its tip..*Gœldia.*
   Maxilla hairy at tip 3
3. Lateral comb of eighth abdominal segment consisting of a few separate scales ....*Limatus.*
   Comb-scales numerous, sometimes attached to a lateral plate .... *Wyeomyia.*

IV. *Tribe Culicini*

This large tribe includes all the common wild and domestic Culicine mosquitoes which are pests to man and animals and all the

Culicine vectors of human diseases. It consists of two main groups, specialized for breeding in different types of water-collections, and several smaller genera, some of which by their structure and habits more or less bridge the gap between the two main groups. The species of one group, consisting of the large genus *Culex* and its specialized off-shoot *Lutzia,* breed in permanent bodies of water, for the most part, and lay their eggs in rafts on the water-surface. The other group centers about the large genus *Aëdes* and also includes a number of derivative genera, *Psorophora* and *Hæmagogus* in America, *Mucidus, Pardomyia, Armigeres, Heizmannia* in the Old World. These forms usually breed in temporary pools, laying their eggs singly in the débris at the bottom of depressions which will later be filled with water. The smaller genera which are intermediate or peculiar forms include *Culicella, Mansonia, Aëdeomyia* and *Orthopodomyia.*

The following keys will serve to differentiate the American genera.

KEYS TO THE AMERICAN GENERA OF THE TRIBE CULICINI

By Adult Characters

1. No bristles on mesonotum just in front of scutellum; wings narrower than the thorax .... *Hæmagogus.*
   Bristles present on mesonotum just in front of scutellum; wings wider than the thorax 2
2. Post-spiracular bristles present 3
   Post-spiracular bristles absent 5
3. Spiracular bristles present, though sometimes small. .*Psorophora.*
   Spiracular bristles entirely absent 4
4. Wing-scales usually narrow; if they are broad there are bristles on the base of the first vein of the wing dorsally......*Aëdes.*
   Wing-scales broad; no bristles on base of first vein dorsally ....*Mansonia* (in part).
5. Spiracular bristles present; base of first vein hairy ventrally .... *Culicella.*
   Spiracular bristles absent; base of first vein scaled or bare ventrally 6
6. Base of first vein without bristles dorsally; wings with a mixture of black and white scales, all broad 7
   Base of first vein with bristles dorsally; wing-scales usually all narrow and dark-colored 9
7. Mid-mesepimeral bristles absent; fourth fore tarsal joint as broad as long ....*Orthopodomyia.*
   Mid-mesepimeral bristles present; fourth fore tarsal joint longer than broad 8
8. Longest scales of wing-fringe longer than the greatest distance from the wing-margin to the sixth vein; antennal joints nearly as broad as long ....*Aëdeomyia.*

Longest scales of wing-fringe shorter than the greatest distance from the wing-margin to the sixth vein; antennal joints much longer than broad .... *Mansonia* (in part).

9. Numerous mid-mesepimeral bristles present .... *Lutzia*.
   Mid-mesepimeral bristles three or less, sometimes absent 10
10. Antennæ much longer than proboscis .... *Deinocerites*.
   Antennæ about as long as proboscis .... *Culex*.

By Larval Characters (Compare Figure 237)

1. Air-tube with a single pair of hairs or hair-tufts ventrally 2
   Air-tube with four or more pairs of hair or hair-tufts ventrally (in the rare cases where hairs or hair-tufts are entirely absent, the air-tube is extremely long and slender 8
2. Air-tube without a basal pecten 3
   Pecten of air-tube present 5
3. Comb-scales few, separate, not preceded by a lateral plate; air-tube short, tapering rapidly to a sharp point .... *Mansonia*.
   Comb-scales numerous, preceded by a lateral plate; air-tube longer and tubular 4
4. Antennæ slender .... *Orthopodomyia*.
   Antennæ more or less inflated .... *Aëdeomyia*.
5. Air-tube with a pair of hair-tufts ventrally at extreme base; pecten usually continued outwardly by a row of long hairs .... *Culicella*.
   Ventral hair-tufts of air-tube on outer half of its length; pecten not continued outwardly by a row of hairs 6
6. Anal segment completely ringed by a chitinous plate; ventral brush continued anteriorly by a series of hair-tufts emerging through small holes in this ring .... *Psorophora*.
   Anal segment often with an incomplete chitinous ring; ventral brush never continued anteriorly by hair-tufts which pierce the ring, if ring is complete 7
7. Only two anal gills present; larvæ breeding only in crab-holes .... *Deinocerites*.
   Four anal gills present; larvæ usually not found in crab-holes .... *Aëdes* and *Hæmagogus*.
8. Large, predaceous larvæ; mouth-brushes made up of stiff, rake-like hairs .... *Lutzia*.
   Smaller larvæ; mouth-brushes composed of slender, flexible hairs .... *Culex*.

V. *Comments on the Genera of the Tribe Culicini*

Aëdes. A very large genus including small or medium-sized mosquitoes, which often have white-banded legs and a thorax marked with stripes or patches of silvery or golden scales. It has been divided into many subgenera, mainly on hypopygial characters. The more primitive subgenera, such as *Howardina, Stegomyia* and *Finlaya,*

usually breed in tree-holes, bromeliads or other collections of water held by plants, while the more typical subgenera (*Ochlerotatus, Culiselsa, Aëdimorphus*) are found in temporary pools produced by rain, melting snow, flooded streams or high tides. The yellow-fever

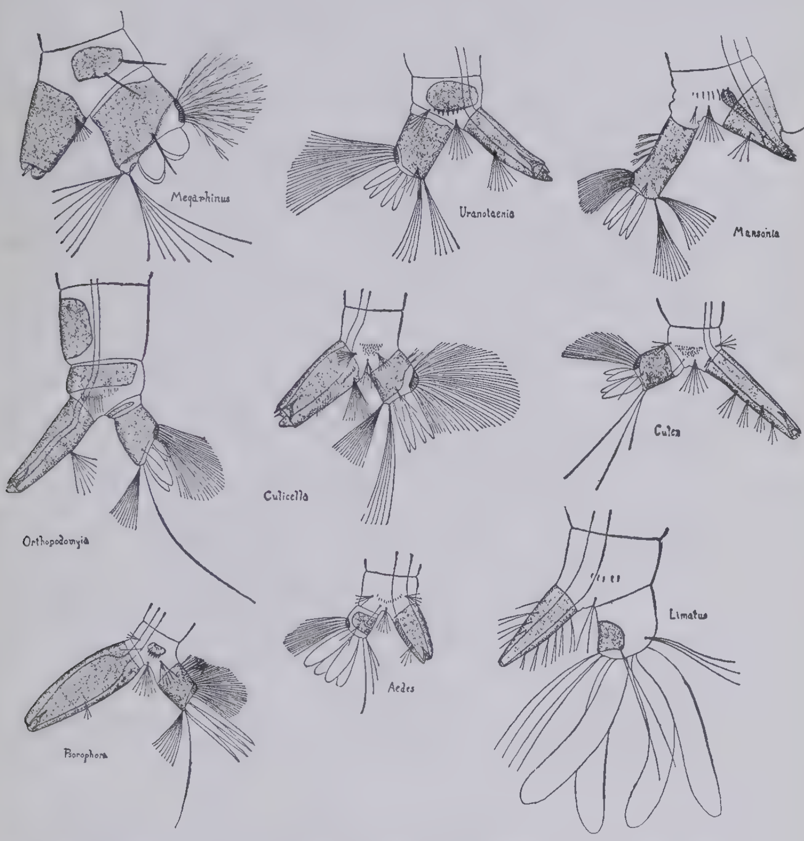


FIG. 237.—Lateral views of the terminal abdominal segments of the mature larvæ of some common genera of Culicine mosquitoes. (Original. Root)

mosquito, *Aëdes* (*Stegomyia*) *ægypti* Linn., is a member of the former group which has become domestic. The common "wood-mosquitoes" of spring and the "salt-marsh mosquitoes" of New Jersey and other coastal regions are examples of the latter group. Some species of *Aëdes* will be found to be common and troublesome in nearly every region of the world. In all species of *Aëdes* and *Psor-*

ophora the female abdomen tapers toward the tip and the terminal *cerci* are prominent and easily seen.

Psorophora. This genus is only found in America. The species all breed in temporary pools, and most of them are vicious biters. It is divided into three groups which are sometimes treated as subgenera. The subgenus *Psorophora* includes very large mosquitoes whose larvæ feed on other mosquito larvæ. The "gallinipper" (*Ps. ciliata*), which ranges from the United States to Argentina, belongs to this group. In the subgenus *Janthinosoma* we find fairly large mosquitoes with dark metallic blue or purplish coloration. The legs are not regularly banded, but some species have one or more of the terminal hind tarsal joints all white. *Ps. posticatus* (including *sayi*) and *Ps. lutzi* are widely distributed species with the last two hind tarsals all white. *Ps. cyanescens* is another species which is troublesome in many regions, but has no white on the hind legs. The larvæ of species of this group never feed on other mosquito larvæ and usually have long antennæ. In the third group, often called the subgenus *Grabhamia,* are found medium-sized or small mosquitoes with much-banded legs and brown or dark gray coloration. Some species have a mixture of dark and light scales on their wings and bear a superficial resemblance to *Mansonia.* The larvæ do not feed on other mosquito larvæ and usually have short antennæ. The species most abundant in the eastern United States is *Ps. columbiæ.*

Hæmagogus. A small genus of tropical American mosquitoes which breed in tree-holes and bamboo. The larvæ are indistinguishable from those of *Aëdes,* but the adults have taken on brilliant metallic blue or purple colors which make them closely resemble certain species of *Sabethes* (subgenus *Sabethoides*).

Culicella. A small genus of fairly large mosquitoes which breed in more or less permanent pools. Most of the species lay their eggs in rafts like *Culex,* but have only one pair of hair-tufts on the larval air-tube, as in *Aëdes.* Many species have indistinct dark spots on the wings, much as in *Anopheles quadrimaculatus.* The species of *Culicella* are found almost exclusively in the north-temperate regions of both the Old and the New Worlds. *C. inornata* is the commonest species of the eastern United States.

Orthopodomyia. A small genus of medium-sized mosquitoes which breed in tree-holes and other collections of water held by plants. Most of them have the legs banded and the thorax striped with white, so that they resemble some species of *Aëdes. O. signifera,* the only species which is found in the United States, has a slight resemblance to the yellow-fever mosquito, and is sometimes mistaken for it.

Species of *Orthopodomyia* are found in most parts of the world, but are usually rare on account of their specialized breeding-places.

Aëdeomyia. This genus includes three species which are widely distributed in the tropics of America, Africa and the Orient, respectively. The adults look like miniature *Mansonia,* but the larvæ are very different. They breed in permanent bodies of water with much surface vegetation, particularly among masses of water-lettuce (*Pistia*) or water-hyacinth (*Eichornia*).

Mansonia. Species of this genus are found all over the world. The adults have white-banded legs and usually a mixture of black and white scales on the wings. The larvæ and pupæ have their air-tubes or breathing-trumpets ending in sharp points, which they thrust into the air-containing tissues of aquatic plants, thus obtaining oxygen without coming to the surface of the water. *M. titillans* is a species which is widely distributed in the American tropics, and whose larvæ and pupæ attach themselves to the roots of the floating water-lettuce (*Pistia*). The only species which is found in the United States (except in Florida) is *M. perturbans,* whose larvæ and pupæ are attached to the roots of sedges.

Culex. A very large genus of small or medium-sized mosquitoes, most of which do not have banded legs nor a distinctly marked thorax. The species of *Culex, Lutzia* and *Mansonia* all lay their eggs in rafts or clumps and the abdomen of the female does not taper toward the tip, which is abruptly truncate, with the cerci hidden. The majority of the species breed in permanent bodies of water, but a few breed in temporary pools and others in bromeliads and tree-holes. The genus has been divided into many subgenera on hypopygial characters. The subgenus *Culex* includes most of the brownish or grayish, medium-sized species which are annoying to man or animals, while the subgenera *Melanoconion, Chœroporpa* and *Mochlostyrax* contain small, black species, which are often found breeding in company with *Anopheles,* but seem to rarely attack man or domestic animals. Some of the tropical American subgenera (*Anœdioporpa, Carrollella, Microculex*) breed only in tree-holes, bromeliads and other water-holding plants.

Two species of the subgenus *Culex* have become domestic mosquitoes, breeding both in ground pools and in all sorts of artificial containers, particularly where the water is more or less polluted. *Culex pipiens* is found in temperate regions all over the world and *C. quinquefasciatus* (or *fatigans*) throughout the tropics and subtropics. In most parts of the world there will also be found other species of this same subgenus which have adopted similar habits to a

greater or less extent. In the eastern United States, for example, *C. territans* and *C. salinarius* are often found breeding in rain-barrels and other containers, as well as in pools.

Lutzia. This genus includes very large mosquitoes, closely related to *Culex,* but with larvæ which prey on other mosquito larvæ. All the species are tropical. The American species have wing-veins with alternating areas of dark and pale scales, much as in *Anopheles.* Other species are found in Africa and the Orient. The larvæ occur either in ground pools or in tanks and other containers, usually feeding on *Culex* larvæ.

Deinocerites. This genus includes a few tropical American mosquitoes which breed only in crab-holes. They do not bite man, but the crab-holes are also inhabited by species of *Culex* and *Aëdes,* some of which do bite human beings.

CHAPTER XL

CULICINE MOSQUITOES AND HUMAN DISEASES

Of the three human diseases transmitted by Culicine mosquitoes, yellow fever and dengue are both carried by a single species of mosquito, *Aëdes* (*Stegomyia*) *ægypti* Linn., while filariasis is known to be borne by a considerable number of different mosquito species.

I. *Yellow Fever*

Yellow fever is an acute, non-contagious, febrile disease, accompanied by albuminuria, hemorrhages and jaundice, and with a high death-rate. Children and negroes usually have the disease in a much milder form than other people. The causative agent is a filter-passing organism. The disease is transmitted in nature only by the bite of the yellow-fever mosquito. To become infected, the mosquito must bite a yellow-fever patient during the first three or four days of illness and it only becomes infective for other persons after the lapse of a period of from twelve to fourteen days.

The original home of both yellow fever and the yellow-fever mosquito was probably on the west coast of Africa. The mosquito has spread all over the tropical and sub-tropical portions of the world (from about 38° North Latitude to about 38° South Latitude), but the disease remained confined mainly to the tropical coastal regions bordering on the Atlantic Ocean, although it did spread also to the Pacific Coast of Central and South America. Since a single attack of yellow fever conferred a lasting immunity, the real endemic centers of the disease were large cities in a warm climate where the mosquito could breed the year round and where there was enough immigration to keep a supply of non-immunes continually present. Such endemic centers were Havana, Cuba; Vera Cruz, Mexico; Colon and Panama City, Panama; Rio de Janeiro, Brazil; Guayaquil, Ecuador, and so on. From these cities the disease was continually being distributed to the surrounding areas and even to temperate regions, where the mosquitoes were able to survive only during the summer. In the days when yellow-fever mosquitoes were carried

everywhere on sailing ships, summer epidemics of yellow fever occurred in such cities as Baltimore, Philadelphia and New York, and even in Quebec, Canada, and Swansea, England. When yellow fever was eradicated from one of the city endemic centers, it ultimately died out in the surrounding regions without any special control measures. Thus, the control work of Gorgas in Havana practically eliminated yellow fever from the West Indies, and the campaign of Oswaldo Cruz in Rio de Janeiro cleaned up all southern Brazil, so far as yellow fever was concerned.

I. THE YELLOW FEVER MOSQUITO

Aëdes ægypti, often popularly referred to simply as the Stegomyia mosquito, is a small, dark mosquito with conspicuously white-banded legs and a rather complicated pattern of narrow silvery lines on the mesonotum (Figure 238). It is the only species of the subgenus *Stegomyia* which is found in America, but in Africa and the Orient there are many other species. It bites both at night and in the daytime, but avoids direct sunlight. It is often very annoying in houses and offices, where it hides under tables or desks and bites people on the ankles or the under sides of the wrists.

The yellow-fever mosquito is the most domestic mosquito known, and breeds almost exclusively in and near houses. It is supposed to have been a tree-hole breeder originally and is still sometimes found in such places, but more often occurs in roof-gutters, wells, tanks, jars and other receptacles in which clean water is stored. It does not usually breed in polluted water and never in ordinary ground pools. Like most tree-hole breeders, the yellow-fever mosquito usually lays her eggs, not on the water surface, but on the wall of the container, just above the water surface. The eggs are able to withstand drying for several months and hatch only after the water rises and submerges them, which assures the larvæ of a good supply of water when they begin their larval life, at least. The larvæ (Figure 239) may be distinguished from those of other American species of *Aëdes* by the "sole-shaped" comb-scales, but are very difficult to differentiate from larvæ of some of the other Old World species of the subgenus *Stegomyia.*

The larvæ are very shy, so that when they are resting at the surface of the water a passing shadow or a slight jar is sufficient to make them hastily retire to the bottom of the container, where they press themselves closely against the bottom or sides. This enables them to breed in containers of drinking-water which are periodically

FIG. 238.—Dorsal and lateral views of the female yellow-fever mosquito, *Aëdes ægypti*. (After Howard)

emptied and refilled, since most of them escape being dipped or poured out because of this reaction. This habit also makes the detection of their presence by inspection more difficult.

In the tropics the yellow-fever mosquito continues to breed throughout the year. Since it breeds mainly in water stored for domestic uses, it is often found in abundance even in arid regions where most other mosquitoes are rare or absent. In the subtropics breeding occurs only in warm weather, and the species may survive the winter either as dry eggs or by means of hibernating females.

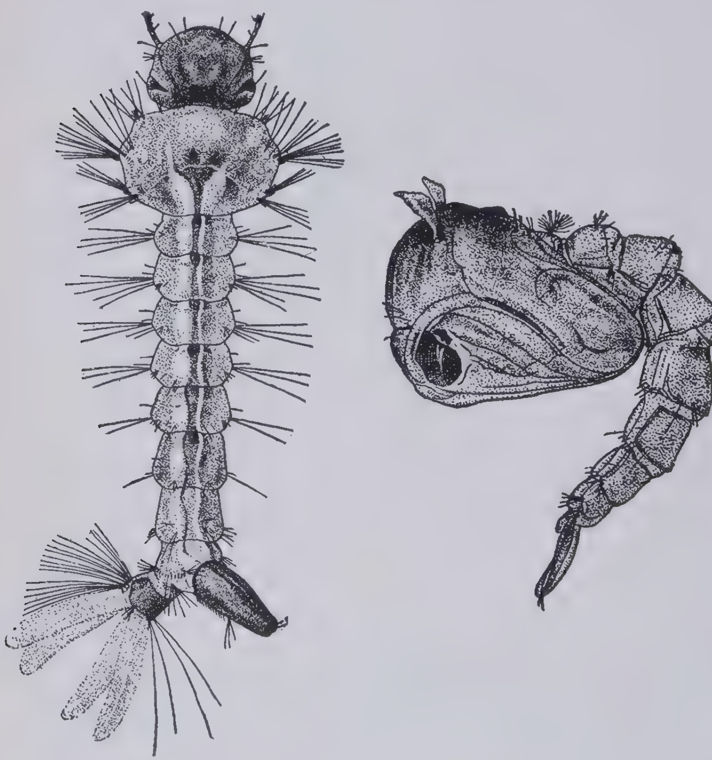


FIG. 239.—Larva and pupa of the yellow-fever mosquito, *Aëdes ægypti.* (After Howard)

The flight of the adult Stegomyia is not strong, and it probably rarely flies more than 100 yards from its breeding-place. They may be carried for long distances, however, on ships or trains.

2. CONTROL

Since mosquitoes must become infected from yellow-fever patients and then must bite healthy persons in order to transmit the disease,

it is obvious that careful screening of both patients and the general population is a measure of value. Since unfavorable breeding-places often produce a crop of very small yellow-fever mosquitoes, the mesh must be fine, not less than eighteen to the inch.

Fumigation of houses in or near which a case of yellow fever has developed, with the idea of destroying mosquitoes which have bitten the patient before they have time to become infective, has also been used and should, theoretically at least, be of value, because of the weak flight of this species.

As in the case of malaria, however, our main reliance in the control of yellow fever is placed in a campaign against the larvæ and breeding-places of the mosquito. This work must be carried on by a definite organization of laborers and inspectors who cover the entire city each week.

All water containers near houses, whether natural or artificial, should be removed or destroyed. Tin cans, broken bottles and jars must be removed. Tree-holes should be filled up or the trees cut down. Roof-gutters may be entirely removed or repaired so that they drain completely.

The greatest effort must be devoted to control of breeding in receptacles used for water-storage inside the houses. Large tanks, wells or cisterns can be covered or screened so that mosquitoes can neither get in nor out. Smaller containers can be emptied and dried in the sun once a week. In arid regions it may be necessary to strain the larvæ out of the water when containers are emptied, in order to save the water. Recently there has been a considerable use of fish control in tanks, cisterns, wells and even in jars and other small containers. Small fish which will eat mosquito larvæ under such conditions may be found in almost any region. Top-minnows are probably one of the best types, since they not only feed voraciously on the larvæ, but also their viviparous reproduction enables them to breed in tanks and cisterns. One great advantage of fish control is the fact that it makes the work of the inspectors much easier and more efficient. Inspectors can detect the presence of fish much more easily than the presence of larvæ, and are justified in assuming that if the fish are still present, larvæ are absent. Another advantage of fish control or the emptying of containers instead of screening or destroying them is that it leaves these favored containers to act as "trap-breeding-places." It must be remembered, also, that the yellow-fever mosquito will breed in almost any sort of collection of reasonably clean water, so that vases of cut flowers, baptismal fonts, tins of water placed under table-legs to keep out ants, and other similar

places must be carefully watched, and emptied or oiled when it is necessary.

It is neither possible nor necessary, in practice, to exterminate the yellow-fever mosquito in any locality. What must be done is to reduce the numbers of mosquitoes to a point where they can no longer carry the disease effectively. It is usually considered that reduction is sufficient when the "Stegomyia index" (the percentage of houses examined in which breeding is found) is reduced to about 1 per cent. This strict control work must be continued for twelve months after the discovery of the last case of yellow fever.

II. *Dengue Fever*

Dengue fever is an epidemic disease which begins very abruptly and is accompanied by intense aches in the head, muscles and joints. Usually a characteristic rash appears after a few days. The disease is painful and temporarily disabling, but lasts for only a few days and is almost never fatal. The causative agent is a filter-passing organism and the insect vector is the yellow-fever mosquito, *Aëdes ægypti*. The former belief that the disease could be carried by *Culex quinquefasciatus* (*fatigans*) has been disproved by recent work. To become infected, the mosquito must bite the patient during the first three days of the disease, and it becomes infective to others in about eleven days after this feed.

Epidemics of dengue fever have occurred at some time or other in nearly every part of the tropics and subtropics. It is likely to be met with wherever the yellow-fever mosquito is abundant. Since it is carried by the same mosquito as yellow fever, nothing further need be said about the vector and its control.

III. *Filariasis*

Filariasis is the infection of man by nematode worms of the Family FILARIIDÆ (see Section II of this book). It is of interest to medical men chiefly because of the probable connection between *Filaria bancrofti* and elephantiasis. Two species of human filarial worms, *Filaria bancrofti* and *Filaria ozzardi*, are known to utilize mosquitoes as intermediate hosts.

1. FILARIA BANCROFTI

This species is of especial interest historically because Manson's discovery (1878) that it was a mosquito which was responsible for

its transmission is one of the great landmarks in the history of Medical Entomology. Cases of infection with *Filaria bancrofti* have been found in nearly all tropical and subtropical regions. Endemic filariasis occurs in the United States only in Charleston, South Carolina.

The adult worms live in the lymphatics and the female sheds the embryos or microfilariæ into the blood. In most cases of filariasis due to *F. bancrofti* the microfilariæ are found in the peripheral circulation in great numbers at night, but retreat to the heart, lungs and larger arteries during the day. This periodicity is very interesting and difficult to explain. It has been shown that the periodicity may be reversed by making a patient sleep by day and work at night for several days. It has also been shown that filarial periodicity is more or less correlated with the habits of the intermediate host. Most strains of *F. bancrofti* exhibit a nocturnal periodicity and are carried by night-biting mosquitoes, particularly *Culex quinquefasciatus.* But in the Pacific Islands there is a strain which exhibits no periodicity and is carried mainly by a mosquito, *Aëdes* (*Stegomyia*) *variegatus,* which bites only by day. It should also be noted that microfilariæ of a related filarial worm, *Loa loa,* exhibit a definite diurnal periodicity and are carried by day-biting tabanid flies of the genus *Chrysops.*

The development of the microfilariæ in the mosquito has already been treated in Section II of this book. It will be remembered that the microfilariæ undergo a period of development in the thoracic muscles of the mosquito and then migrate into the proboscis sheath or labium. While comparatively little is known about mosquitoes as intermediate hosts of filarial worms, it has been shown that the microfilariæ are not able to develop equally well in all mosquitoes. In the work of Bahr (1912) in the Fiji Islands, for example, he found that when microfilariæ were taken in by *Aëdes* (*Stegomyia*) *variegatus* they developed rapidly and practically all of them reached maturity and migrated into the proboscis. In *Culex quinquefasciatus* (*fatigans*), development was slower and only two or three microfilariæ completed their development in each mosquito, while in *Culex annulirostris* and *Aëdes* (*Stegomyia*) *ægypti* the microfilariæ developed very slowly for a time and then degenerated in the thoracic muscles of the mosquito without ever attaining maturity.

Although *Culex quinquefasciatus* and *Aëdes variegatus* are probably the most important intermediate hosts of *Filaria bancrofti,* the development of the microfilariæ has been recorded in a number of other mosquitoes and there must be many more species which are

capable of acting as intermediate hosts, but have never been experimentally tested. The following list of species which have been tested is thus by no means a complete list of the species which are capable of transmitting filariasis:

1. Complete development of microfilariæ to the proboscis stage has been observed in:
   - *Anopheles subpictus* Grassi and *gambiæ* Giles (*costalis* Theo. nec. Loew).
   - *Culex pipiens* Linn. and *quinquefasciatus* Say (*fatigans* Wied).
   - *Aëdes* (*Stegomyia*) *variegatus* Doleschal.
   - *Mansonia uniformis* Theo.
2. Apparently normal development of microfilariæ (but not including actual observation of the proboscis stage) has been observed in:
   - *Anopheles hyrcanus* Pallas, *barbirostris* Van der Wulp, *argyritarsis* Rob.-Des. and *albimanus* Wied.
   - *Culex gelidus* Theo., *sitiens* Wied., and *bitaeniorhynchus* Giles.
   - *Aëdes* (*Stegomyia*) *desmotes* Giles, *perplexus,* Leic., *albopictus* Skuse, and *albolineatus* Theo.
   - *Mansonia annulipes* Walker.
3. Partial development, never resulting in the proboscis stage, has been observed in:
   - *Anopheles maculipennis* Wied.
   - *Culex annulirostris* Skuse.
   - *Aëdes* (*Stegomyia*) *ægypti* Linn. (*Stegomyia fasciata* Fabr.)

2. CONTROL

Control of *Filaria bancrofti* is to be based, evidently, on the control of the mosquito intermediate host, and the same general principles already brought out in regard to the control of malarial and yellow-fever mosquitoes will apply. In any given region the principal mosquito vector or vectors must be determined and their habits and breeding-places studied before efficient control work can be undertaken. Where the domestic species of *Culex* are the main carriers, control would be much like yellow-fever control, but with especial attention to breeding-places containing polluted water. In the Oceanic Islands, on the other hand, where *Aëdes variegatus* is the most important vector, attention must be centered on coconut shells, cacao pods, natural and artificial cavities in trees and artificial containers with clean water.

Other Filarial worms which are carried by mosquitoes: The evidence at present available indicates that *Filaria ozzardi* of man is

transmitted by mosquitoes. It is also known that *Dirofilaria immitis* of dogs is carried by mosquitoes. In the case of this latter species the microfilariæ develop, not in the thoracic muscles, but in the Malpighian tubules of the mosquito.

CHAPTER XLI

OTHER BLOOD-SUCKING NEMATOCERA (FAMILIES CHIRONOMIDÆ, PSYCHODIDÆ, SIMULIIDÆ)

Besides the CULICIDÆ, three other families of the NEMATOCERA include species which feed on vertebrate blood. These forms are all considerably smaller than mosquitoes and are often lumped together by those whom they annoy under the general name of "sand-flies." All three groups include species which are vicious biters and often extremely troublesome. Species belonging to all of the groups have been definitely implicated in the transmission of human diseases.

Family CHIRONOMIDÆ (Midges) Subfamily CERATOPOGONINÆ ("punkies" or "sand-flies"). The family CHIRONOMIDÆ includes a very large number of genera and species, most of which are of medical interest only because the pupæ and adults are sometimes confused with the corresponding stages of mosquitoes.

The subfamilies of the CHIRONOMIDÆ may be distinguished by the following key, adapted from Malloch (1915).

KEY TO THE SUBFAMILIES OF THE CHIRONOMIDÆ

1. Thorax projecting over head; sternopleura enlarged and extending below the tips of the fore coxæ 2
   Thorax not projecting over head; sternopleura not enlarged and not extending to the tips of the fore coxæ; antennæ usually with 15 joints in both sexes; no cross-vein connecting fourth and fifth veins; fourth vein forked..........*Ceratopogoninæ.*
2. Antennæ with fifteen joints in both sexes; cross-vein between fourth and fifth veins presents..................*Tanypinæ.*
   Either cross-vein between fourth and fifth veins absent or antennæ of female with eight or less joints......*Chironominæ.*

I. *Ceratopogoninæ*

The subfamily CERATOPOGONINÆ includes all the blood-sucking forms of the family. There are many different genera in the subfamily, only three of which are known to feed on vertebrate blood, although others are thought to feed mainly or in part on the blood of insects and other invertebrates.

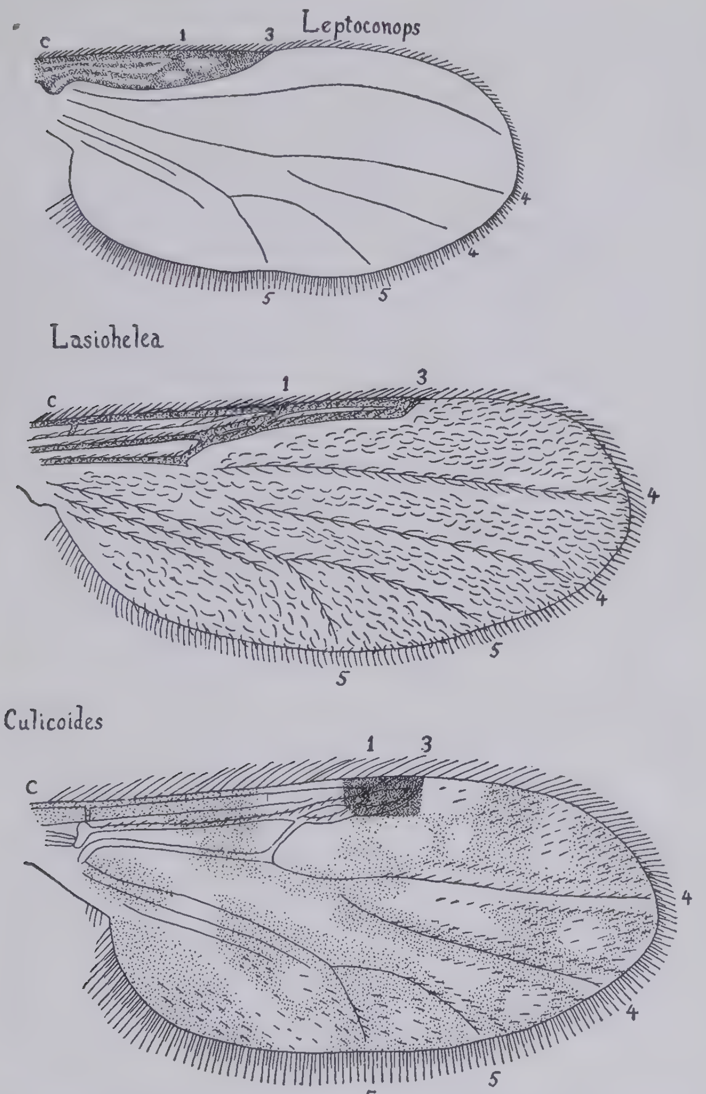


FIG. 240.—Wings of the three blood-sucking genera of the subfamily Ceratopogoninæ. C, costa; 1, first vein; 3, third vein; 4, 4, fourth vein; 5, 5, fifth vein. (Original. Root)

Some characteristics of importance in distinguishing between the genera are the following. The *empodium*, between the claws at the tip of the leg, may be well-developed or practically absent. The wing-venation varies in different genera (see Figure 240). The costa ends before the tip of the wing. The second vein is absent and the first and third veins run into the costa at or near its tip. The third vein arises from the first vein about the level of the conspicuous cross-vein which usually connects the base of the third vein to the fourth vein. The first and third veins may be separate for their entire length when the cell between them is called the *radial cell*. Often they are fused or connected at one point, forming two *radial cells* of which the one nearest the base of the wing is called the *first*, the other the *second*. The vestiture of the wing-membrane is often important, also. Nearly all genera have the wing-membrane evenly dotted with very minute hairs called *microtrichiæ*. In addition to these there may or may not be larger hairs, which are called *macrotrichiæ* when they are comparatively short and straight, *recumbent hairs* when they are longer and are curved so that their tips lie close to the wing-membrane.

The following key will enable one to identify the three blood-sucking genera with certainty and also includes a few of the commoner non-blood-sucking genera.

KEY TO SOME OF THE GENERA OF THE CERATOPOGONINÆ

1. Wing-membrane with microtrichiæ and also with many long recumbent hairs 2
   Wing-membrane with microtrichiæ and sometimes with short macrotrichiæ also, but never with long recumbent hairs 4
2. Empodium well developed, hairy, as long as claws 3
   Empodium reduced or absent; radial cells small or practically absent .... *Dasyhelea*.
3. Third vein not extending beyond middle of wing; first radial cell obliterated, second very short .... *Forcipomyia*.
   Third vein extending beyond middle of wing; first radial cell small or nearly obliterated, second long and narrow .... *Lasiohelea*.
4. An extra vein apparently present between third and fourth veins .... *Leptoconops*.
   No extra vein between third and fourth veins 5
5. Only one long radial cell present.................. *Bezzia*, etc.
   Two distinct radial cells present 6
6. Wings with microtrichiæ only .... *Stilobezzia*, etc.
   Wings with microtrichiæ and also with at least a few macrotrichiæ near tip of wing 7

7. Empodium well developed; second radial cell much longer than first; wings not spotted .... *Atrichopogon.*
Empodium absent; both radial cells about the same length; wings usually spotted .... *Culicoides.*

I. BLOOD-SUCKING GENERA

Culicoides. Includes a large number of blood-sucking species, distinguished from each other mainly by the different color patterns of the wings and mesonotum. Most of the species have the wings characteristically spotted or dappled, but several species with unspotted wings are known. The small species, *Culicoides furens* Poey, which breeds in and near mangrove swamps, is a great pest in many coastal regions of South and Central America.

The larvæ live in water or in water-saturated sand or soil. Some species breed in brackish water, others in fresh-water pools, others in tree-holes or water-holding plants. The larvæ are very long and slender, whitish or yellowish in color, and swim readily with a rapid vibratory movement. The pupæ are brown and are often found floating at the surface of the water.

Leptoconops. Species of this genus are not as frequently met with as is *Culicoides,* but they may be locally abundant. The head and thorax of adults are usually black, the abdomen and wings whitish. The larvæ are shorter, broader and less active than those of *Culicoides,* and usually live in wet sand or soil.

Lasiohelea. Species of this genus are found in many different parts of the tropics, but are not usually abundant. The early stages are not known.

The blood-sucking CERATOPOGONINÆ are often extremely annoying, but have not been incriminated in the transmission of any important disease. Sharp (1927) states that in Nigeria *Culicoides austeni* is the intermediate host of the human filarial worm *Acanthocheilonema perstans.*

II. *Psychodidæ*

Family PSYCHODIDÆ ("moth-flies") genus *Phlebotomus* ("sand-flies"). The family PSYCHODIDÆ contains a number of genera, some of which, *Psychoda,* for example, include a very large number of species from all parts of the world. In the United States one form, *Psychoda alternata* Say, has come into considerable prominence because of the tremendous numbers of this species which often breed in sprinkling filter beds used for the purification of sewage.

In this family the wing-veins are thickly fringed with long hairs and the body and legs are covered with hairs or scales. The wings have six or sometimes seven longitudinal veins, of which the second is usually three-branched and the fourth forked. Cross-veins are present only at the extreme base of the wing. The only blood-sucking genus is *Phlebotomus,* which may be distinguished from the other

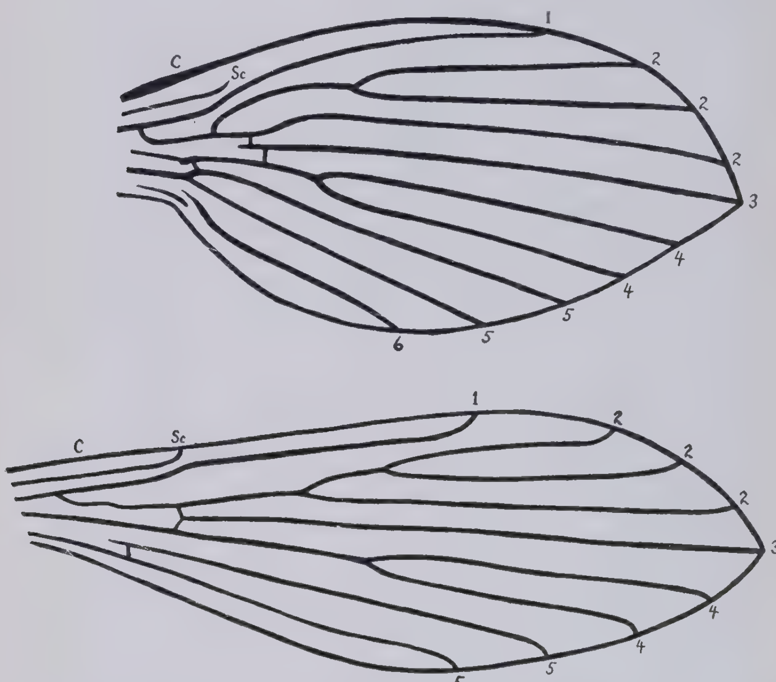


FIG. 241.—Wing venation of *Psychoda* (above) and *Phlebotomus* (below). C, costa; Sc, subcosta; 1, first vein; 2, 2, 2, second vein; 3, third vein; 4, 4, fourth vein; 5, 5, fifth vein; 6, sixth vein. (Original. Root)

genera by the fact that the first forking of the second vein is near the middle of the wing instead of near the base (see Figure 241). The anterior one of the two branches formed by this first bifurcation forks again before reaching the wing margin. The species of *Phlebotomus* also have longer and more slender bodies, wings and legs than the typical Psychodids, and usually hold their wings flat together and erect in repose, while the more typical members of the family fold them roof-like over the abdomen, like tiny moths.

I. PHLEBOTOMUS

This genus includes a considerable number of species, found in all of the warmer parts of the world. All the species are of small size and some of them are the most minute blood-sucking Diptera known. Identification of the different species depends very largely on the male hypopygia, especially on the number and arrangement of the strong spines on the terminal segment of the most dorsal of the three pairs of clasper-like appendages (see Figure 242). It is often impossible to identify a species from females alone, although the comparative lengths of the different segments of the five-jointed palpi, of the various portions of the second wing-vein, and so on, may show characteristic differences in different species.

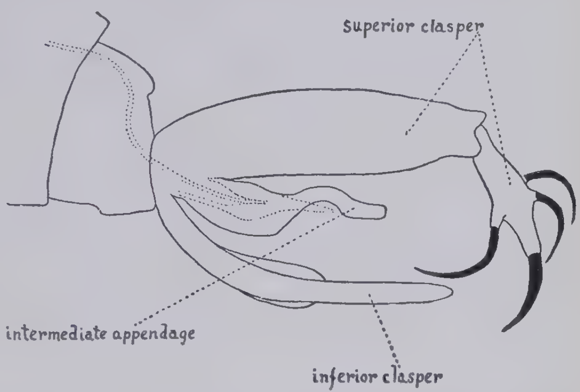


FIG. 242.—Left half of the male hypopygium of *Phlebotomus migonei*. (Original. Root)

The following key to the American species of *Phlebotomus* is adapted from Larrousse (1921) and is based primarily on the male hypopygial structures.

KEY TO THE AMERICAN SPECIES OF PHLEBOTOMUS

1. Superior claspers of male with four spines on the terminal joint. 2
   Superior claspers of male with five spines on the terminal joint. 9
2. Terminal spine the longest of the four 3
   Terminal spine shorter than some of the others......*P. migonei.*
3. The four spines arranged in two groups of two spines each...... 4
   At least one of the four spines isolated from the others........ 6
4. Intermediate appendages with two strong spines..*P. longipalpis.*
   Intermediate appendages without any spines 5
5. Fifth segment of palpi the longest ....*P. intermedius.*
   Fifth segment of palpi shorter than the second and third segments ....*P. rostrans.*
6. Superior claspers of male with an apical group of three spines on terminal joint 7

No apical group of three spines on terminal joint of superior claspers of male 8
7. A tuft of hairs on the basal joint of the superior claspers .... *P. walkeri.*
No such tuft of hairs present ....*P. squamiventris*
8. A basal group of three spines present on terminal joint of superior claspers ....*P. verrucarum.*
One basal and one terminal spine present, with a group of two spines between them ....*P. atroclavatus.*
9. A tuft of hairs on the basal joint of the superior claspers .... *P. brumpti.*
No such tuft of hairs present .... *P. vexator.*

The larvæ and pupæ of *Phlebotomus* are very minute and difficult to find. They occur in situations which have a solid substratum of stone, concrete or hard earth, which is kept dark and damp. Such places are the interior of stone walls or piles of rock, the walls of caves and cesspools or deep cracks in the earth. In attempting to locate the breeding-places of *Phlebotomus* it is not advisable to search for larvæ and pupæ. A better plan is to cover over a small portion of a suspected area with a cage of fine-meshed gauze or cloth and examine the cage each morning to see whether any adults have bred out.

The adults of *Phlebotomus* are so minute that they are able to pass through most screens and bed-nets without difficulty, but they cannot fly against even a light wind and ordinarily appear only on windless nights. Recent studies indicate that their range of flight is very limited indeed. Some authors believe that they never fly more than a few yards from their breeding-place.

2. PHLEBOTOMUS AS A DISEASE-CARRIER

Pappataci fever (sand-fly fever, three-day fever) is transmitted by *P. pappatasii* Scopoli and probably by other species as well. The disease is very much like dengue, but usually of shorter duration. The causative agent is a filter-passing organism. The disease is prevalent in the Mediterranean and Oriental regions and may be more widely distributed.

Recently attention has been directed toward species of *Phlebotomus* as probable vectors of Oriental sore and kala azar, diseases caused by protozoans of the genus *Leishmania* (see Section I of this book). The evidence for the transmission of Oriental sore by *Phlebotomus* is fairly satisfactory, but the vector of kala azar is still in doubt. Sinton (1925) has shown that a comparison of the dis-

tribution of these two diseases with the distribution of the Oriental species of *Phlebotomus* suggests that *P. sergenti* is most concerned in the carriage of Oriental sore, while *P. argentipes* should be investigated in connection with kala azar.

Townsend has reported that *P. verrucarum* is the vector of Oroya fever and Verruga peruviana (which he considers to be only two stages of the same disease) in certain parts of Peru.

3. CONTROL

Although it is possible to avoid the bites of *Phlebotomus* by the use of very fine-meshed screens or bed-nets, electric fans and repellent ointments, the destruction of breeding-places is probably the most satisfactory control measure. The area that must be controlled is comparatively small, due to the weak flight of these flies. Stone walls and the like may be faced with mortar or cement, earth-cracks filled and tamped and walls of cesspools periodically sprayed with kerosene or some other larvicide.

III. *Simuliidæ*

These flies are rather small and of robust build, with short, strong legs and short, broad wings. In the wings (Figure 243), the costa does not extend to the tip of the wing. The second and third veins may both be present, but usually are fused together to form a single vein. The costa, subcosta, first, second, and third veins and the base of the fourth vein are prominent and concentrated near the anterior margin of the wing. The other veins are weak and difficult to distinguish from the folds which are also present. The antennæ are short and bare; the compound eyes are separated in females but larger and meeting in the mid-line in males. The thoracic color pattern of males and females of the same species is often very different. The females often attack man and animals in swarms. Frequently the bite itself is entirely painless, but an itching ulcer-like sore appears later at the seat of each bite.

The larvæ and pupæ live in swift running streams, attached to leaves or stones. The larvæ are elongate and somewhat swollen posteriorly (Figure 244). They usually stand upright, attached to the substratum by a large sucker armed with rows of hooklets which is at the extreme posterior end of the body. Ventrally, just behind the

head is a short *proleg* tipped by a smaller sucker. The head bears, in addition to the usual mouth parts, a pair of large fan-like processes which bear a close resemblance in structure and function to the mouth brushes of mosquito larvæ.

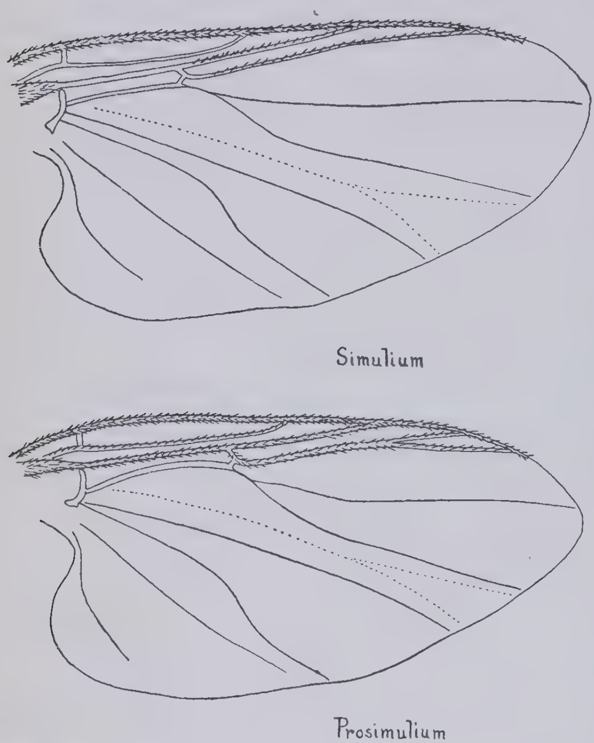


Fig. 243.—Wings of *Simulium* and *Prosimulium*. (Original. Root)

The larva contains a pair of long silk-glands, and is able to spin silken threads, which it uses in attaching itself during its larval life and out of which it constructs a *cocoon* shaped like a "wall-pocket," before pupation. The pupa is attached to the cocoon only by rows of hooklets on the abdominal segments, which become entangled in the threads of the cocoon. From the sides of the thorax of the pupa arise the long, chitinized respiratory filaments, each of which is usually branched. The number of branches and mode of branching of these filaments is usually characteristically different in different species.

I. CLASSIFICATION

While many authors still consider that the family SIMULIIDÆ includes only the single genus *Simulium*, the recent revision of the North American SIMULIIDÆ by Dyar and Shannon (1927) recognizes the four genera mentioned in the following key, adapted from their paper.

KEY TO THE NORTH AMERICAN GENERA OF SIMULIIDÆ

1. First vein hairy dorsally throughout its length 2
   First vein hairy dorsally at base and tip, but bare between humeral cross-vein and cross-vein connecting the third and fourth veins .... *Simulium.*
2. First vein joining costa at middle of the length of the latter .... *Parasimulium.*
   First vein joining costa near its tip 3
3. Both second and third veins present.............. *Prosimulium.*
   Second and third veins fused into one .... *Eusimulium.*

2. SIMULIIDÆ AS DISEASE-CARRIERS

The black-flies have been known and dreaded for many years because of the effects of their bites. It is said that during the American Civil War, cattle, horses and mules died in large numbers as a result of their attacks. Stokes (1914) has made a study of the lesions caused by the bites of *S. venustum* Say, and of the character of the salivary toxin which produces the lesions.

Blacklock (1926) has recently shown that *S. damnosum* is the intermediate host of the human filarial worm, *Onchocerca volvulus* of Africa. It is probable that some species of this family also act as intermediate hosts for the related form, *Onchocerca cæcutiens,* of Mexico and Guatemala. Robles (1919) reports that the presence of this latter parasite in the human body gives rise to a condition known locally as "Coast erysipelas" and may also lead to blindness.

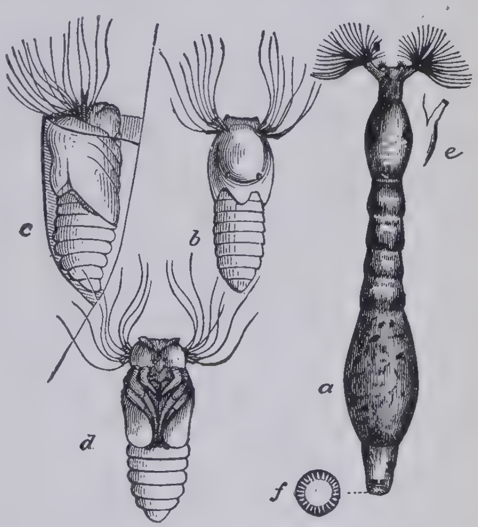


FIG. 244.—Larva and pupæ of *Simulium.* (After Osborn)

CHAPTER XLII

SUBORDER ORTHORRHAPHA, SECTION BRACHYCERA, FAMILY TABANIDÆ

In contrast to the Section NEMATOCERA, most of whose members are small flies, the Section BRACHYCERA includes a number of families of comparatively large flies, many species being over an inch in length. The only family of medical importance is the family TABANIDÆ, whose species are commonly called "horse-flies," "deer-flies," "mangrove-flies" and "Seroots."

I. *Characteristics*

Some species of the family are as small as an ordinary house-fly, but the majority of them are larger, some much larger. The females of many species are vicious biters, but the males are incapable of biting, as is the case in blood-sucking NEMATOCERA. As a rule, it is only the smaller genera and species which attack human beings habitually. The larger forms usually obtain blood from the larger domestic and wild animals.

The head is large, usually as wide as the thorax, with very large compound eyes which meet in the mid-line in males but are separated in females. In life the eyes are often brilliantly colored or patterned, but these colors usually disappear completely in dried specimens. The antennæ are usually described as three-segmented, but the third joint is made up of a large basal portion and from three to seven smaller *annuli* or *rings* (Figure 245) which probably really represent antennal segments. The number of annuli of which the third segment is composed and the comparative lengths of the first and second segments are valuable in distinguishing the different genera. The *proboscis* or mouth part complex is usually rather short, but may be longer than the whole body in certain species.

The mouth parts of the larger species of the family are excellent objects for the study of the different portions of the piercing and sucking mechanism. The blade-like *mandibles* work like scissors in

piercing the skin, and the protrusion and retraction of the rod-like, toothed *maxillæ* serve to further lacerate the tissues. The blood is sucked up through a tube formed by the apposition of the grooved *epipharynx* and the flat *hypopharynx*, within the latter of which the salivary duct may be seen. All these structures lie in the dorsal groove of the proboscis sheath or *labium*, which has at its tip a pair of large *labellæ* whose inner surfaces bear a system of *pseudo-tracheal tubules* for sucking up water and other liquids, similar to those which are found in the non-biting flies of the house-fly type. To the bases of the maxillæ are attached a pair of two-segmented *maxillary palpi*.

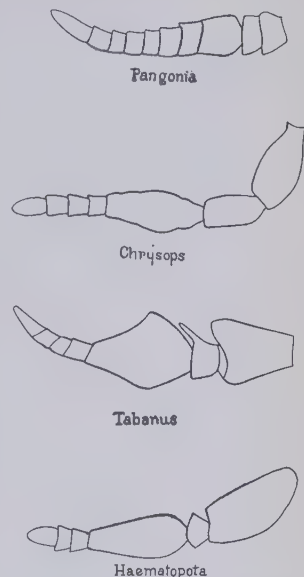


FIG. 245.—Antennæ of some common genera of Tabanidæ. (Original. Root)

The wings have the same general type of venation as the other members of the Section BRACHYCERA (Figure 246). The first, second and sixth veins are unbranched, the third and fifth fork into two branches and the fourth first forks and then the anterior branch forks again, making three branches. Cross-veins connect the costa with the subcosta, the third vein with the anterior branch of the fourth and the posterior branch of the fourth vein with the anterior branch of the fifth. There is also a cross-vein connecting the second branch of the fourth vein with

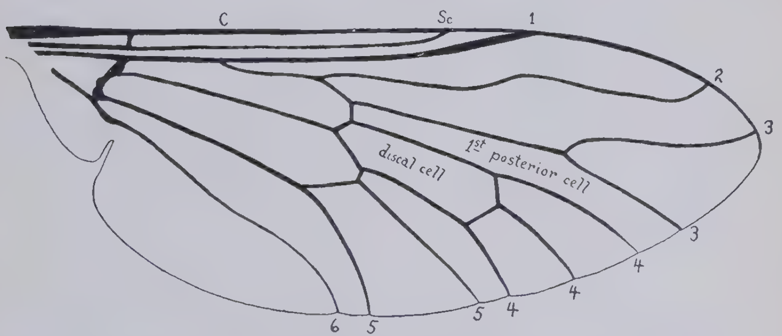


FIG. 246.—Wing venation of a Tabanid fly. C, costa; Sc, subcosta; 1 to 6, first to sixth veins. (Original. Root)

the third branch of the same vein, which aids in forming a completely enclosed cell in the middle of the wing (*discal cell*). The tips of the sixth vein and the posterior branch of the fifth are approximated or even fused for a short distance. The wings of Tabanids may be perfectly clear, entirely suffused with dark pigment, or else spotted or marbled with pigment to produce more or less definite patterns, which are sometimes characteristic of certain genera or species.

The thorax and abdomen are stout and usually hairy, often black, brown or yellowish in color, sometimes with definite whitish or dark markings on the abdomen. The legs are strong and the *empodium* between the claws at their tips is a hairy pad like the pulvilli. There may or may not be long, spine-like *spurs* at the tips of the tibiæ of the hind legs.

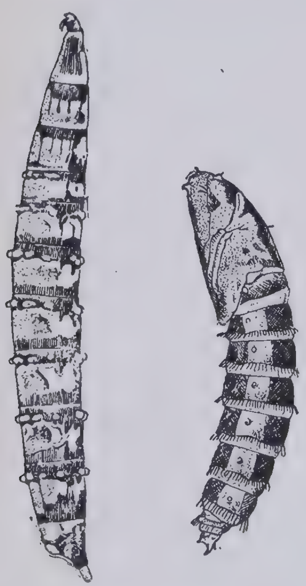


FIG. 247.—Larva and pupa of *Tabanus*. (After Neave)

II. *Life History*

The eggs of the TABANIDÆ are usually laid in large masses on aquatic plants or rocks which overhang water. When the larvæ hatch they drop into the water and soon burrow into the mud at the bottom. The larvæ are elongate, tapering toward both ends and usually have each of their segments more or less completely encircled by a series of protuberances armed with hooklets (Figure 247). They feed voraciously on all sorts of small, soft-bodied insect larvæ and other similar organisms, and will destroy each other if two larvæ are kept in the same receptacle. As they grow older they wander into drier and drier situations, finally pupating just below the surface of the ground, often some distance away from the pond or stream where they began their larval life. The pupa is much like the chrysalis of a butterfly, with a hard, chitinous covering, and has rings of backwardly-pointing spines on its abdominal segments. Development is comparatively slow. In the tropics, the entire cycle may be completed in four months or so, but in temperate regions a year or even two years seems to be required.

III. *Classification*

The family TABANIDÆ includes more than sixty genera, but over half of these include only from one to five species and are found only in one particular part of the world. The following key, adapted from a larger one given by Surcouf (1921), includes all the widely distributed and important genera, as well as some others which are often met with in America.

KEY TO SOME OF THE GENERA OF THE FAMILY TABANIDÆ

1. Hind tibiæ without spurs; ocelli rudimentary or absent ....(subfamily TABANINÆ) 2
   Hind tibiæ with spurs; three ocelli usually present ....(subfamily PANGONINÆ) 6
2. Third joint of antenna with a basal portion and three annuli .... *Hæmatopota.*
   Third joint of antenna with a basal portion and four annuli..... 3
3. Basal portion of third antennal joint with a dorsal tooth or process 4
   Basal portion of third antennal joint without any dorsal projection 5
4. Basal portion of third antennal joint with a slender dorsal process; body rather slender ....*Dichelacera.*
   Basal portion of third antennal joint with a massive dorsal tooth; body stout ....*Tabanus.*
5. Thorax and abdomen dark, with iridescent green tomentum .... *Lepidoselaga.*
   Thorax and abdomen yellowish, without any green tomentum .... *Diachlorus.*
6. Third joint of antenna with a long basal portion and four annuli 7
   Third joint of antenna with a short basal portion and seven annuli 8
7. First and second joints of antenna both long and of about equal length .... *Chrysops.*
   Second joint of antenna short, about half as long as first joint .... *Silvius.*
8. Upper corner of eye acutely angled in female..........*Goniops.*
   Upper corner of eye not acutely angled in female 9
9. Proboscis not longer than palpi..................*Apatolestes.*
   Proboscis longer than palpi, often much longer 10
10. Tips of second branch of third vein and first branch of fourth vein fused together for a short distance ....*Pangonia, Esenbeckia, Erephopsis,* etc.
    Tips of these veins not fused together 11
11. Eyes hairy ....*Diatomineura.*
    Eyes bare ....*Corizoneura.*

IV. *Notes on Some Genera of Tabanidæ*

1. HÆMATOPOTA

Although this large genus has a world-wide distribution, species and individuals are most numerous in Africa and the Orient, less so in Europe and comparatively rare in America. The species are fairly large and usually have the wings delicately mottled with gray.

2. TABANUS

The largest genus of the family, including over a thousand species, occurring in every part of the world. It includes some small species which attack man, but most of the species are large and feed mainly on domestic animals. The wings are most often clear, but many species show a small amount of dark spotting and a few have the wings mostly or entirely dark.

3. DIACHLORUS AND DICHELACERA

Two smaller genera, almost entirely confined to the American tropics. Both have a generally yellowish or brownish coloration. In *Diachlorus* the wings are mainly clear, with indistinct infuscated areas along the anterior margin and at the tip. The species are small and often attack man. In *Dichelacera,* the species average somewhat larger and the wings are usually extensively mottled with brown and yellow.

4. LEPIDOSELAGA

A small genus (four species) found in Tropical America. The species are very small and frequently bite man. The wings are mainly dark on their basal two thirds, with the terminal third clear.

5. CHRYSOPS

A large genus, found all over the world, the species being particularly numerous in temperate as well as tropical America. The species are all fairly small. Usually the wings are clear, with a narrow dark area along the anterior margin and a broad dark bar across the wing at the level of the discal cell or just beyond it. The tip of the wing may be clear or more or less completely dark. These "deer-flies" bite man readily and have been shown to be the vectors of two human diseases.

6. SILVIUS

A smaller but very widely distributed genus. Species are particularly numerous in the Australian region. Many of them have a superficial resemblance to the smaller species of Tabanus.

7. PANGONIA

The genera *Pangonia* and *Corizoneura* have a world-wide distribution, while *Esenbeckia* is found only in South America and *Erephopsis* and *Diatomineura* occur mainly in South America and Australia. All these species are of fairly large size and have unusually long probosces. In many species the proboscis is longer than the body. It has sometimes been stated that these "long-beaked" Tabanids bite while hovering on the wing, but this is probably erroneous. Several species have been observed to settle on the bodies of domestic animals and insert their long proboscis into the skin at an acute angle. The wings may be clear but are often somewhat infuscated throughout their extent.

V. *Tabanids as Disease-Carriers*

1. LOA LOA

The filarial worm, *Loa loa,* is not infrequently found in man on the west coast of Africa. The adult parasite wanders about through the connective tissues and may produce "Calabar swellings" or cause trouble by entering the conjunctiva. The microfilariæ or embryos occur in the blood, as do those of *Filaria bancrofti,* but are present in the peripheral circulation only by day instead of only at night. Leiper (1912) and the Connals (1922) have shown that the microfilariæ develop normally in *Chrysops silacea* and *C. dimidiata,* undergo partial development in *Hæmatopota,* and do not develop at all in *Tabanus, Stomoxys* and *Glossina.* Apparently normal development of the microfilariæ of *Loa loa* has also been reported in *Chrysops centurionis.*

2. TULARÆMIA OR DEER-FLY FEVER

Tularæmia is a plague-like disease of rodents, caused by *Bacterium tularense,* and readily transmissible to man. It was originally found affecting ground-squirrels in California and is apparently present among rabbits in many different parts of the United States.

In laboratory experiments it is readily transmitted from one animal to another by various biting flies, lice, fleas, bedbugs and ticks. Human beings may become infected by skinning or handling infected rodents. In Utah and Idaho, Francis (1922) has shown that the disease is carried from jackrabbits to man by *Chrysops discalis*. Since the disease is so widely distributed among rabbits and is so easily transmissible to man (it is said that every one who has worked with the disease in the laboratory for any length of time has ultimately contracted it), it seems peculiar that more human cases are not reported.

3. DISEASES OF DOMESTIC ANIMALS

Since the larger Tabanid flies feed mainly on domestic animals, and are frequently shaken off by one animal and forced to complete their interrupted meal from another member of the herd, it is natural to find that they may transmit mechanically various diseases whose causative agents occur in the blood, such as anthrax and trypanosomiasis. Most of the cattle trypanosomes of tropical Africa are normally carried by tsetse flies (*Glossina*), but they are sometimes transmitted by Tabanids, especially in regions where the tsetse flies are not found. *Trypanosoma evansi* (causative agent of "Surra") seems to be ordinarily transmitted by Tabanids, and is found only in areas where *Glossina* is absent. It is not improbable that other trypanosome diseases of horses and cattle, which occur in Tropical America and the Orient, are transmitted in a similar manner.

4. CONTROL

Nets, smudges and repellant dips or sprays have been used to protect domestic animals from the attacks of Tabanids and other biting flies, but no serious control of Tabanids seems to have been attempted. Portchinski pointed out that newly-emerged Tabanids promptly seek out certain pools for the purpose of drinking, and claimed that considerable numbers of the flies could be destroyed by oiling the surface of these pools with kerosene.

CHAPTER XLIII

SUBORDER CYCLORRHAPHA. GENERAL SURVEY

The Suborder CYCLORRHAPHA includes a large variety of flies, most of which are non-blood-sucking forms. Several of the groups into which it is divided may be discussed very briefly, while others are of considerable importance to the medical entomologist.

I. *Section Aschiza*

The flies belonging to this section have their pupæ enclosed in puparia formed from the last larval skin and emerge by pushing off a circular cap at the anterior end of the puparium, but the *ptilinum,* whose protrusion accomplishes this, is comparatively small and the scar left when it is retracted is in the form of a crescent-shaped *frontal lunule* only. The only family of any medical interest is the SYRPHIDÆ or "flower-flies," all of which show a "false-vein" in the wing, between the third and fourth veins. Larvæ of the genus *Eristalis* have sometimes been found in the human stomach, where they may produce quite severe symptoms. The larvæ of *Eristalis* are often called "rat-tailed maggots," because of the very long and slender breathing tube at the posterior end of the body. They usually live in heavily polluted water. The adults of this genus are often found about flowers and are called "drone-flies" because of their superficial resemblance to male honey-bees.

II. *Section Schizophora*

In this section the *ptilinum* is larger and the scar left when it is retracted forms a *frontal lunule* and a pair of *frontal sutures,* lateral to the antennæ, as well. The antennæ and wing-venation show only slight variation in different families. The antennæ consist of two short and one long segments, the latter with a dorsal *arista* near its base. Usually the antennæ are bent down and closely applied to the face, so that the morphologically *dorsal* arista really projects anteriorly. In the wing, the costa does not extend to, or extends only

slightly beyond, the tip. The subcosta (sometimes absent), and the six other veins all appear unbranched, although the fifth vein is really forked. Its posterior branch, however, has fused with the sixth vein for nearly all of its length, leaving independent only a short portion near the base of the wing which looks like a cross-vein. For convenience we usually refer to this compound vein simply as the sixth vein. Sometimes a short and indistinct seventh vein is present. Often the tips of the fifth and especially the sixth vein do not extend to the wing-margin.

This section is divided into two tribes, ACALYPTERÆ and CALYPTERÆ.

1. TRIBE ACALYPTERÆ

The Acalyptrate muscoid flies, as they are often called, have the little *squamæ* or calypteræ at the bases of the wings very small and almost imperceptible. The subcosta is sometimes well developed, but often reduced or practically absent. The majority of the flies in this tribe are small, decidedly smaller than an ordinary house-fly.

Many of the flies of this tribe may be lumped together under the two categories of "dung-flies," which breed in fecal matter, and "fruit-flies," which breed in decaying fruit. A few genera of dung-flies, such as *Sepsis* (Family SEPSIDÆ) and *Borborus* (Family BORBORIDÆ) are sometimes found in houses. The fruit-flies of the genus *Drosophila* (Family DROSOPHILIDÆ) are often found about fruit, especially bananas, in stores and houses. Some species of this genus frequent fecal matter as well as fruit, and might perhaps carry intestinal diseases. The tiny "eye-flies" of the Family OSCINIDÆ, are often extremely annoying because of their habit of crawling on the skin or darting into the eye in search of perspiration and other liquids. Some of them have been suspected of carrying eye diseases. But in general, the ACALYPTERÆ contain no species of very great medical interest.

2. TRIBE CALYPTERÆ

The Calyptrate muscoid flies have well developed squamæ and the subcosta is never reduced. The majority of the species are about the size of a house-fly or larger. Many of the forms included in this tribe are of great medical importance, and must be treated in more detail in future chapters. They may affect human health in three ways. First, there is a small group of blood-sucking genera (Family MUSCIDÆ, *Stomoxys* group) which includes the tsetse-flies, vectors of African sleeping sickness. Second, there are many non-biting

domestic flies (belonging to the Families MUSCIDÆ, ANTHOMYIDÆ, CALLIPHORIDÆ and SARCOPHAGIDÆ) which frequent both human feces and human food, and may therefore carry intestinal diseases of many kinds. And, in the third place, there are many species whose larvæ either must or may live as parasites in the natural cavities or the tissues of men and animals, sometimes producing severe symptoms. This condition is called *myiasis*. In the Family ŒSTRIDÆ, the larvæ of all the species are parasitic, mainly in wild and domestic animals. Larvae of various species belonging to the Families SARCOPHAGIDÆ, CALLIPHORIDÆ, MUSCIDÆ and ANTHOMYIDÆ have been found in the bodies of man and animals, also.

III. *Section Pupipara*

The flies of this section are all ectoparasites, living mainly on birds and mammals. They reproduce by depositing a single mature larva at a time, which pupates at once. Some of them are wingless. Their sac-like, not definitely segmented abdomens, and their reduced antennæ, which appear to consist of only a single joint bearing a tuft of hairs, are characteristic. They feed on the blood of their hosts, but rarely or never bite human beings. They are of medical interest only because some of the species are vectors of diseases of lower animals which are related to human diseases.

CHAPTER XLIV

THE CALYPTRATE MUSCOID FLIES. STRUCTURE AND CLASSIFICATION

The Calyptrate muscoid flies are one of the most highly developed and recently-evolved groups of insects. In fact, we might almost say that evolution is still in progress in this group, meaning that in it the intermediate and transitional forms which are absent in other groups of flies are here still present in many cases. This makes their classification more difficult and necessitates the use of minute and apparently inconsequential characters for the identification of genera and species.

The following discussion of the adult anatomy is by no means exhaustive, and is intended primarily to serve as a glossary of terms used in the keys.

I. *The Head*

The head bears the large *compound eyes* laterally, the three *ocelli* or simple eyes dorsally, the proboscis ventrally and the antennæ anteriorly. Various regions of the head, particularly on its anterior surface, have been given names, although they are not definitely delimited from each other.

The dorsal region of the head, between the eyes, is called the *vertex* and bears two pairs of large *vertical bristles*. The *ocelli* lie in a triangular *ocellar plate,* from which arise the *ocellar bristles.* Anteriorly, the region between the eyes, extending from the ocellar plate above to the *frontal lunule,* just above the bases of the antennæ, is called the *frons* or *front*. It is subdivided into a central region, the *frontalia,* extending laterally almost to the *frontal bristles* and two narrow lateral regions, the *parafrontals,* between the frontalia and the eyes. The parafrontals bear the *fronto-orbital bristles*.

The rest of the anterior surface of the head, from the frontal lunule to the *oral margin,* that is, the edge of the opening through which the proboscis protrudes, is called the *face*. From the ends of the frontal lunule there extend downward and outward the *frontal sutures*. The whole arched scar formed by the frontal lunule and the

frontal sutures is sometimes called the *ptilinal suture*. It is, of course, the scar left after the withdrawal within the head of the protrusible sack called the *ptilinum*, which the fly used in breaking its way out of the puparium. Within the area enclosed by the ptilinal suture are the *antennal grooves*, in which the antennæ lie. Between the antennal grooves and the suture there is, on either side, a well-developed *facial ridge*, bearing the *facial bristles*. At their lower ends the facial ridges bend inwardly to form the *vibrissal angles* from which arise a pair of very strong bristles, the *vibrissæ*. The narrow regions between the eyes and the frontal sutures are called the *parafacials* and bear the *facio-orbital bristles*. Ventrally, the regions between the lower edges of the eyes and the oral margin are called the *cheeks* or *buccas*. This area is often hairy and these hairs are sometimes called, collectively, the *beard*.

The posterior surface of the head is called the *occiput* and contains the *occipital foramen* or neck opening.

II. *The Proboscis*

The mouth parts or proboscis of the muscoid flies are made up of three portions. The basal joint or *rostrum* contains the sucking apparatus and may be considered a portion of the head which has become protrusible. Although the *maxillæ* have entirely disappeared, the maxillary *palpi*, which in these flies consist of only a single joint, have become attached to the rostrum. The middle portion of the proboscis, called the *haustellum*, corresponds to the *labium* of the horse-fly, minus the labellæ but plus the *epipharynx* and *hypopharynx*, which lie in a dorsal groove and form a food-canal. At the tip of the haustellum are the paired *labellæ*, forming the terminal portion of the proboscis. In the non-blood-sucking forms the labellæ, when opened out, form a large, spongy mass whose heart-shaped terminal surface is covered with rows of *pseudo-tracheal tubules* into each of which liquid food may be sucked through a double row of tiny perforations. From the pseudo-tracheal tubules the food passes into larger collecting ducts which lead to the *mouth* or *stoma* in the center of the labellæ. Around the mouth lies a V-shaped *discal sclerite* from which arise a few small, weak *prestomal teeth*.

In the blood-sucking muscoid flies the labellæ become much smaller and the pseudo-tracheal tubules ultimately disappear, while the prestomal teeth become much stronger and more numerous, so that they are capable of scarifying and finally even of piercing the skin of man and animals. In these forms, also, the haustellum be-

comes more heavily chitinized and usually elongate and slender. What really amount to stages in the evolution of such a specialized proboscis as that of *Glossina* may be seen by studying first the proboscis of the house-fly, *Musca,* then that of the Oriental *Philæmatomyia,* and then that of our common biting stable-fly, *Stomoxys* (compare Figure 250).

III. *The Antennæ*

In all the muscoid flies, the antennæ are of essentially the same type, consisting of two short basal joints and an elongate third joint which bears a dorsal *arista* near its base. The differences between the antennæ of different groups are in minor details, especially in the vestiture of the arista, which may be *bare, pubescent* (covered with short hairs), *pectinate* (Figure 252) (with a single row of bristles dorsally), or *plumose* (Figure 224) (with rows of bristles both dorsally and ventrally).

IV. *The Thorax*

As in all DIPTERA, the mesothorax is greatly enlarged and makes up the greater part of the thorax. Dorsally a *transverse suture* separates the *prescutum* from the *scutum.* Posterior to the scutum is a smaller *scutellum.* On each side of the mesonotum there are three indistinctly separated prominences called the *humeral callus,* the *prealar callus* and the *postalar callus* (see Figure 248).

Laterally, the thorax shows four main sclerites, the *mesopleura, sternopleura, pteropleura* and *hypopleura.* The thoracic openings of the respiratory system, the *prothoracic spiracle* (between the propleura and mesopleura) and the *post-thoracic spiracle* (posterior to the hypopleura) are also laterally situated. From the taxonomic viewpoint, the greatest significance of these thoracic sclerites comes from the use in classification of the number of bristles in the various groups, which often bear the names of the sclerite or callus upon which they are located. Figure 248 gives a diagrammatic representation of the thoracic sclerites and bristles of one of these flies, and will serve much better than a description to indicate their positions.

V. *The Wings*

The wing venation of a muscoid fly is shown in Figure 249. There is comparatively little variation in the venation of different genera. The most important point to note, probably, is the form

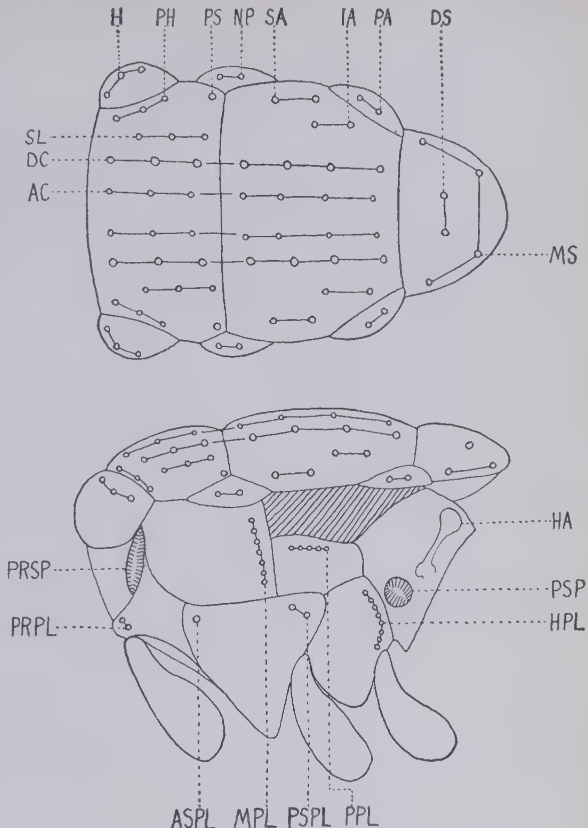


FIG. 248.—Dorsal (above) and lateral (below) views of the thorax of a Muscoid fly, to show the locations of the various bristles. AC, acrostichal row of bristles, divided into anterior (or pre-sutural) acrostichals and posterior (or post-sutural) acrostichals; ASPL, anterior sternopleural bristles; DC, dorsocentral row of bristles, divided into anterior (or pre-sutural) dorsocentrals and posterior (or post-sutural) dorsocentrals; DS, discal scutellar bristles; H, humeral bristles (on the humeral callus); HA, haltere; HPL, hypopleural bristles (on the hypopleura); IA, intra-alar bristles; MPL, mesopleural bristles (on the mesopleura); MS, marginal scutellar bristles; NP, notopleural bristles (on the notopleural callus); PA, post-alar bristles (on the post-alar callus); PH, post-humeral bristles; PPL, pteropleural bristles (on the pteropleura); PRPL, propleural bristles; PRSP, prothoracic spiracle; PS, pre-sutural bristle; PSP, postthoracic spiracle; PSPL, posterior sternopleural bristles; SA, supra-alar bristles; SL, sublateral row of bristles. (Original. Root)

of the tip of the first posterior cell, which is determined by the degree of curvature or angling of the terminal section of the fourth vein. The presence or absence of a row of hairs on the bases of the first and third veins is also a valuable character. The base of the first vein, from the base of the wing to about the level of the *humeral cross-vein* (connecting costa and subcosta) is sometimes called the *stem vein.* On the under side of the base of the wing may be seen a small, triangular *subcostal sclerite,* extending from the subepaulet to the first vein. At the base of the costa there are sometimes two little overlapping scale-like structures. The one nearest the body is called the *epaulet* and the other the *subepaulet* or *basicosta.* The color and vestiture of these little structures are sometimes important. If the

wing is stretched forward to its full extent (as in Figure 249), one can see that its posterior border is continued basally beyond the wing proper in the form of three membranous lobes. The one nearest the wing is the largest and resembles the wing-membrane in appearance. It is called the *alula*. The other two are usually opaque, often whitish in color, and are called the *squamæ* or *calyptræ*. The upper *squama* (nearest to the alula) is usually smaller than the *lower squama*. When the wing is laid back along the abdomen, the upper squama is folded back so that it lies upside down just above the lower squama, the dorsal surfaces of both being in apposition with each other. The

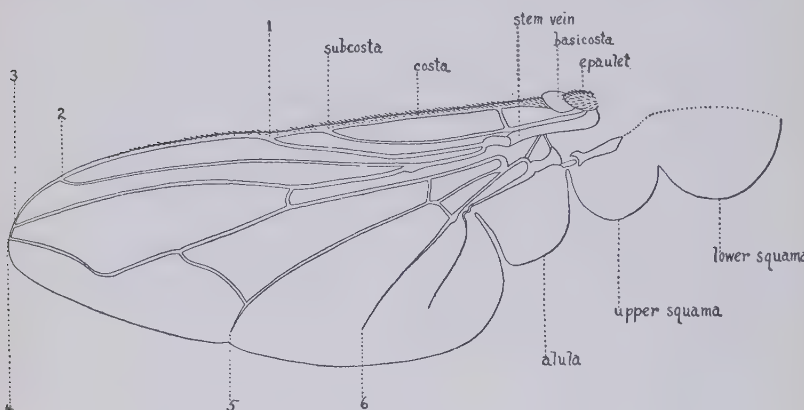


FIG. 249.—Wing of *Musca domestica*. (Original. Root)

margins of the squamæ are usually hairy but the presence or absence of hairs on the upper or lower surfaces may be a characteristic of value.

VI. *The Abdomen*

The number of visible segments in the abdomen varies considerably; often there are only four or five. In the females of some species, the ordinary house fly for example, the four terminal abdominal segments form a long slender *pseudo-ovipositor,* and lie, telescoped together, inside of the abdomen and entirely out of sight except while the fly is depositing its eggs. In some other species no such structure is present. In male muscoid flies the terminal segments of the abdomen are modified to form the hypopygium, or external genitalia. The form of these structures is often of great importance for identification. In fact, in certain genera which include

a very large number of similar species, *Sarcophaga* for example, it may be practically impossible to identify the species by any other characters. Those interested may consult Aldrich (1916) and Shannon (1923, 1924) for figures of male hypopygia and further details.

VII. *Life History*

The majority of the muscoid flies lay eggs. In some few species or groups the eggs hatch within the body of the female and larvæ are deposited instead of eggs. Sometimes the larvæ do not increase in size while in the uterus of the female fly. In the genus *Sarcophaga,* for example, all the species which have been studied deposit a large number of first-stage or newly-hatched larvæ. In some other flies the larvæ undergo a certain amount of growth in the uterus. Some species deposit a small number of second-stage larvæ, and in *Glossina,* only a single larva develops at a time and it is retained within the body of the female fly until it has reached the third stage and is ready to pupate. The flies of the section PUPIPARA have the same method of reproduction as does *Glossina.*

The larvæ of the muscoid flies (see Figure 257) are legless, worm-like "maggots," with very small and unchitinized heads. Normally the posterior end of the body is large and truncate while the anterior end is tapering. Each segment of the body may show *spinose areas,* which sometimes form a complete ring around the body. The second segment from the anterior end bears, in second-stage and third-stage larvæ, a pair of small hand-like *anterior spiracles.* The truncate posterior end of the larva bears the *anus,* with its *anal tubercles,* ventrally, and the pair of darkly-chitinized *posterior spiracles* dorsally. The posterior spiracles lie in an area called the *stigmal field,* which is sometimes depressed to form a slight pit or even invaginated, forming a pocket. When the stigmal field is depressed it is bounded by a ridge which usually bears several pairs of tubercles.

The larvæ of the muscoid flies always live under conditions which surround them with a supply of food which they can obtain with very little effort on their own part. Many breed in masses of decaying plant or animal matter or in fecal material. Others have become adapted for a parasitic existence in the bodies of snails, insects or mammals. The various species of *Sarcophaga* show a particularly wide range in their choice of larval habitats.

In the case of the typical filth-breeding and carrion-breeding flies, which include all the common domestic species, the mature larvæ

tend to migrate when they are full-fed, probably because the optimum conditions for their larval life are not suited to pupation and pupal existence. At any rate, when the larvæ are ready to pupate they tend to leave the manure or carrion in which they have been feeding and burrow into the earth or sand to pupate. As will be pointed out later, this habit must be taken into account in planning control measures for the domestic flies.

The pupa of the muscoid flies is of the *coarctate* type. That is, it has no heavy chitinous covering of its own, but is enveloped and protected by the last larval skin, contracted and hardened to form what we call a *puparium*. This puparium is usually elongate-ovoid in shape and yellow to dark brown or black in color. It is absolutely motionless, resembling a seed. Most of the larval structures, such as anterior and posterior spiracles, spinose areas and tubercles, can be seen more or less distinctly in the puparium. When the adult fly is ready to emerge, it breaks off a circular cap at the anterior end of the puparium by the repeated expansion and contraction of its *ptilinum* (see page 471).

VIII. *Classification*

In the key to the families of the DIPTERA (page 474) are given the diagnostic characteristics of the families MUSCIDÆ, ANTHOMYIDÆ, CALLIPHORIDÆ, SARCOPHAGIDÆ, TACHINIDÆ, DEXIIDÆ and ŒSTRIDÆ. But it should be emphasized that the dividing lines between these families are not always clearly marked, so that some genera have been shifted from one family to another and then back again, perhaps. An entirely satisfactory arrangement has not yet been reached.

In order to get a general view of the possible relationships of these Calyptrate muscoid flies, it is convenient to think of them as centering about the *Musca* group of the family MUSCIDÆ. From this group, which includes such genera as *Musca, Morellia, Cryptolucilia, Pyrellia* and *Myiospila,* we may think of the lines of evolution as radiating out in several directions. The most obvious connection is with the blood-sucking *Stomoxys* group, through the genus *Philæmatomyia*. This line may be considered as culminating in *Glossina* and the HIPPOBOSCIDÆ. In another direction, the genera of the *Muscina* group provide a transition to the ANTHOMYIDÆ. And, passing over to the CALLIPHORIDÆ, which until recently were considered to be a group of the family MUSCIDÆ, we find the genera of true blow-flies, such as *Calliphora, Lucilia, Phormia* and *Cochliomyia* trending toward the SARCOPHAGIDÆ, while

Pollenia shows some affinities with the TACHINIDÆ and DEXIIDÆ and the African *Cordylobia* and its allies resemble the ŒSTRIDÆ, particularly in their larval structure and habits.

The key given earlier in this section (page 474) will serve for the allocation of specimens to families. The following keys to the genera of MUSCIDÆ, CALLIPHORIDÆ and ŒSTRIDÆ will enable the identification of adults belonging to the more common and important genera. For the identification of genera and species of SARCOPHAGIDÆ, the student is referred to the monograph by Aldrich (1916). Keys to the species of North American CALLIPHORIDÆ are given by Shannon (1923, 1924) and will be found very useful for this region.

KEY TO IMPORTANT GENERA OF THE FAMILY MUSCIDÆ

1. Haustellum of proboscis long, slender, chitinized; labellæ small.. 2
   Haustellum of proboscis shorter, stout, usually not well chitinized; labellæ large, with a well developed system of pseudotracheal tubules 8
2. Antennal arista with plumose bristles above; three sternopleural bristles present; base of fourth vein deeply curved..*Glossina*.
   Antennal arista with simple bristles above and sometimes below also; only one or two sternopleural bristles; base of fourth vein nearly straight 3
3. Antennal arista pectinate, with bristles above only 4
   Antennal arista plumose, with bristles both above and below... 6
4. Palpi much shorter than proboscis; bases of first and third veins hairy ....*Stomoxys*.
   Palpi as long as proboscis 5
5. First posterior cell narrowed at wing-margin; base of first vein bare; base of third vein hairy ....*Stygeromyia*.
   First posterior cell widely open; bases of first and third veins both bare ....*Hæmatobia*.
6. Bases of first and third veins hairy ....*Lyperosiops*.
   Bases of first and third veins bare 7
7. First posterior cell narrowed at wing-margin; palpi slightly spatulate ....*Hæmatobosca*.
   First posterior cell widely open; palpi strongly spatulate .... *Bdellolarynx*.
8. Antennal arista bare (*Synthesiomyia*) or pectinate (*Hemichlora*).
   Antennal arista plumose 9
9. Middle tibiæ with one or more prominent bristles on inner side beyond middle 15
   Middle tibiæ without prominent bristles on inner side beyond middle 10
10. Tip of fourth vein with a more or less rounded angle......... 11
    Tip of fourth vein gently curved 12
11. Haustellum of proboscis well chitinized; prestomal teeth rather large and prominent ....*Philæmatomyia*.

Haustellum of proboscis weakly chitinized; prestomal teeth very small ....*Musca*.
12. Eyes hairy 13
Eyes bare 14
13. Sternopleural bristles none in front, two behind....*Graphomyia*.
Sternopleural bristles two in front and two behind..*Myiospila*.
14. One or more pairs of anterior acrostichal bristles and bristles on outer side of hind tibia present...................*Muscina*.
Anterior acrostichal bristles and bristles on outer side of hind tibia absent ....*Morellia*.
15. First vein extending beyond the level of the cross-vein connecting the fourth and fifth veins................*Mesembrina*.
First vein ending before the level of the cross-vein connecting the fourth and fifth veins 16
16. Sternopleural bristles one in front and two behind .... *Cryptolucilia*.
Sternopleural bristles one in front and three behind....*Pyrellia*.

KEY TO IMPORTANT GENERA OF THE FAMILY CALLIPHORIDÆ

1. Eyes hairy ....*Somalia, Neocalliphora, Tyreomma*.
Eyes bare 2
2. Vibrissal angle well above oral margin 3
Vibrissal angle at about same level as oral margin 7
3. Sternopleural bristles one in front and one behind 4
Sternopleural bristles two in front and one behind 5
4. Body grayish, with yellow, woolly hairs among the bristles .... *Pollenia*.
Body metallic, without yellow, woolly hairs ....*Chrysomyia*.
5. Body metallic green or blue; parafacials hairy throughout 6
Body black or dark metallic gray; parafacials bare or hairy only above ....*Neopollenia*.
6. Post-thoracic spiracle light colored; palpi large..*Compsomyiops*.
Post-thoracic spiracle dark; palpi small..........*Cochliomyia*.
7. Species wholly metallic blackish, bluish or greenish in color 8
Species brownish or yellowish in color 13
8. Base of first vein hairy above; subcostal sclerite with small black bristles 9
Base of first vein bare above; subcostal sclerite with minute hairs only 11
9. Disc of upper squama bare; anterior acrostichal bristles distinct. 10
Disc of upper squama thinly hairy; anterior acrostichal bristles not distinct; prothoracic spiracle black........*Protophormia*.
10. Four intra-alar bristles; prothoracic spiracle dark or black .... *Protocalliphora*.
Two intra-alar bristles; prothoracic spiracle light orange .... *Phormia*
11. Upper side of lower squama bare.......................*Lucilia*.
Upper side of lower squama distinctly hairy 12
12. One sublateral bristle ....*Cynomyia*.
Three sublateral bristles ....*Calliphora*.

13. Large robust flies; abdomen elongate; parafacials with several rows of hairs; abdomen with well developed bristles; eyes of males widely separated 14
Not fitting the above description 15
14. Pteropleural bristles distinct ....*Auchmeromyia.*
No pteropleural bristles ....*Bengalia.*
15. Parafacials with several rows of hairs ....*Cordylobia.*
Parafacials bare ....*Mesembrinella*, etc.

KEY TO IMPORTANT GENERA OF THE FAMILY ŒSTRIDÆ

1. Fourth vein of wing straight, not extending to the margin of the wing ....*Gasterophilus.*
Fourth vein of wing curved forward at tip, narrowing or closing the first posterior cell 2
2. Tips of third and fourth veins fused together, closing the first posterior cell ....*Œstrus.*
Tips of third and fourth veins not fused, leaving the first pos terior cell narrowly open 3
3. Antennal arista bare 4
Antennal arista pectinate 5
4. Proboscis reduced; palpi absent ....*Hypoderma.*
Proboscis well developed; palpi present ....*Bogeria.*
5. Tarsal joints of legs broad, flat and hairy; alula of wing large .... *Cuterebra.*
Tarsal joints of legs slender, not very hairy; alula of wing moderate ....*Dermatobia.*

CHAPTER XLV

BLOOD-SUCKING MUSCIDÆ AND HIPPOBOSCIDÆ

The blood-sucking genera of the family MUSCIDÆ form a compact group, beginning with the genus *Philæmatomyia,* which can hardly be distinguished from *Musca* and leading up to such specialized forms as the tsetse flies of the genus *Glossina,* which show many resemblances to the Pupiparous flies of the family HIPPOBOSCIDÆ.

The blood-sucking MUSCIDÆ are particularly characteristic of the Oriental and African regions, where a great variety of genera and species are to be found. Except for the genus *Glossina,* most of them breed in horse or cow dung and feed on animals much more often than on man. Two species of this group, *Stomoxys calcitrans* and *Hæmatobia irritans,* although probably originally Oriental, have become distributed all over the world, wherever domestic horses and cattle are present. These are the only common blood-sucking MUSCIDÆ of the Americas.

With the exception of the notorious tsetse flies of the genus *Glossina,* none of the blood-sucking MUSCIDÆ have been definitely incriminated as carriers of human diseases. It is believed, however, that some of them do serve, at times, as vectors of certain parasites and diseases of domestic animals.

I. *Stomoxys calcitrans Linn. The Biting Stable-Fly*

This species is of much the same size and general appearance as the ordinary house-fly (*Musca domestica*), but may readily be distinguished from it by its piercing proboscis (Figure 250) and curved (not angled) fourth vein. It is abundant nearly everywhere and bites man as well as animals freely.

Its preferred breeding-place seems to be decaying vegetable matter, such as rotting hay or straw, but it will breed in stable manure if there is a decided admixture of straw or other bedding material. Severe outbreaks of this fly have usually been traced to the presence of large piles of rotting straw. Control, of course, centers on the

destruction of such breeding-places by scattering or burning the straw. It is advisable, also, to take measures to prevent breeding in horse manure.

Although *Stomoxys* was once suggested as a possible carrier of pellagra (Jennings and King, 1913) and two cases are on record where poliomyelitis was transmitted from monkey to monkey by this

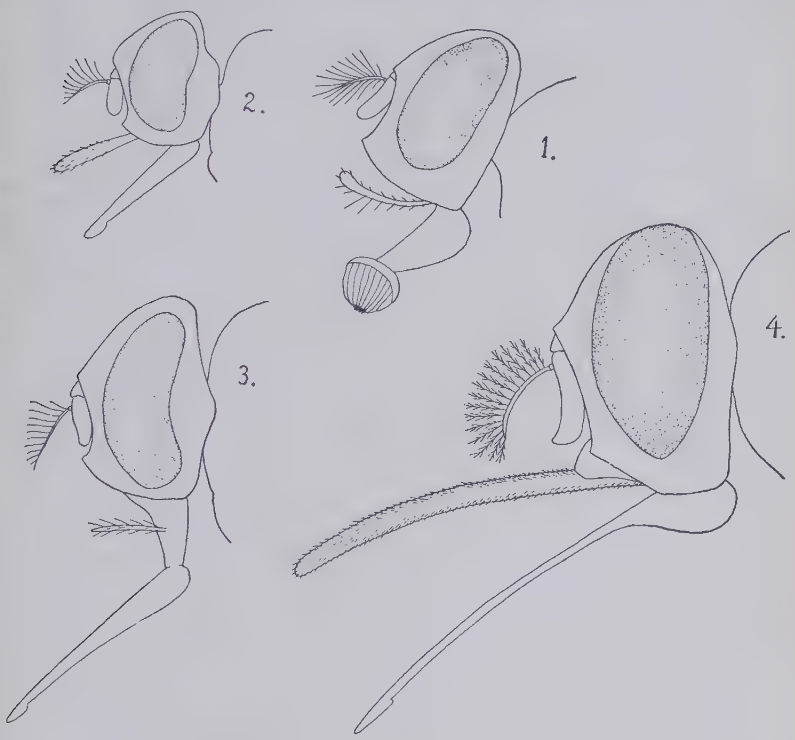


Fig. 250.—Profile views of the heads of some blood-sucking Muscoid flies. 1, *Philæmatomyia crassirostris*; 2, *Hæmatobia irritans*; 3, *Stomoxys calcitrans*; 4, *Glossina palpalis*. (Original. Root)

fly (Rosenau and Brues, 1912, Anderson and Frost, 1912), this species is not believed at present to be concerned in the transmission of any disease of human beings. As regards domestic animals, however, it has been shown to be capable of transmitting anthrax (Mitzmain, 1914) and infectious anemia of horses (Scott, 1922), so that it may be of considerable importance to the veterinary entomologist.

II. *Hæmatobia irritans* Linn. *The Horn-Fly*

The horn-fly is only about half as large as a house-fly or stable-fly and also differs from the latter species by having the palpi longer than the proboscis (Figure 250). It was introduced into the United States at Philadelphia about 1885, and spread rapidly, so that in 1892 it was found all over the country east of the Rocky Mountains. Two years later it reached California.

This species feeds almost exclusively on cattle and breeds only in cow manure. Since it almost never bites human beings, it is not of medical importance.

III. *Genus Glossina, the Tsetse Flies*

The genus *Glossina* includes about twenty species, all inhabiting tropical Africa, south of the Sahara, except that one species

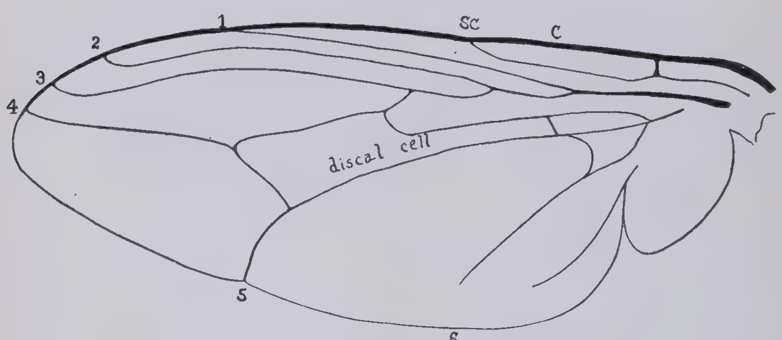


FIG. 251.—Wing venation of *Glossina*. (Original. Root)

(*G. tachinoides*), which has a wide range in Africa, is also found in the southern tip of the Arabian peninsula. The important species of the genus are not much larger than a house-fly, but some of the rarer and less important ones are considerably larger.

Flies of the genus *Glossina* may be easily identified by noting the slender proboscis with its bulbous base and ensheathing palpi (Figure 250); the *branched* dorsal bristles of the antennal arista (Figure 252); and the decided curvature of the base of the fourth vein of the wing (Figure 251), which makes the discal cell have a shape something like a butcher's cleaver. The wings are long and in

life are laid flat, one above the other, when the fly is at rest. They project considerably beyond the tip of the abdomen.

The species are very similar to each other and not easy to identify. For full details, consult the monographs by Austen (1911) and Newstead (1924).

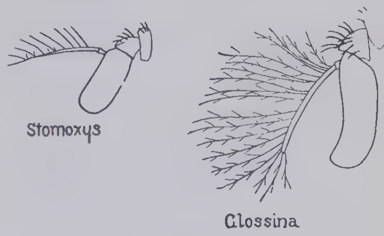


FIG. 252.—Antennæ of *Stomoxys* and *Glossina.* (Original. Root)

Several species of *Glossina,* particularly *G. morsitans* Westwood, are known to be the usual vectors of Nagana and other trypanosome diseases of domestic animals. *G. morsitans* and the closely related *G. swynnertoni* are the vectors of Rhodesian sleeping sickness of man (caused by *Trypanosoma rhodesiense*) and *G. palpalis* and perhaps *G. tachinoides* are vectors of Gambian sleeping sickness (caused by *Trypanosoma gambiense*).

1. GLOSSINA PALPALIS ROB.-DES.

This species is rather generally distributed in the wet jungle country of West and Central Africa, ranging from Senegal to Angola on the west coast and extending into the interior to Lake Victoria and Lake Albert. It is found only in the immediate neighborhood of water and where the undergrowth is dense. It seems to be especially abundant at fords and boat-landings or along native paths, where human blood is readily accessible.

The female selects sandy beaches or loose soil for larviposition, places which have suitable soil and are densely shaded and near water being preferred. It bites by day, but not at night.

2. GLOSSINA MORSITANS WESTWOOD

This species was the original tsetse fly and its bite was known to be fatal to domestic animals long before the causative trypanosome had been discovered. It inhabits the belt of savannah or park land around the edges of the wet jungles where *palpalis* flourishes. Its range extends south to Rhodesia and Zululand, up through the lake region to the Anglo Egyptian Sudan and thence west to Senegal. It is not uniformly distributed, but occurs in localized areas, or "fly-belts," which expand and contract their limits with the changing seasons. It bites by day but not at night, like *palpalis.* The females

select loose soil under fallen trees or limbs which do not quite touch the ground as their favorite place of larviposition.

The control of tsetse flies is particularly difficult because of their mode of reproduction. In all other DIPTERA, the easiest method of control is to kill the larvæ or abolish the breeding-place. In the case of *Glossina,* the adult female carries the larva in her body, so that it cannot be reached. Measures for destroying adults have been tried. On the island of Principe (DaCosta, 1916) success was attained by the use of men carrying fly-paper on their backs, but elsewhere this method has not been successful. Specially trained "fly-boys" are able to catch large numbers of adults, but not, apparently, to exterminate the flies in this way. The question of whether it is possible to drive out the flies by destroying the game animals on which they feed is still a hotly-debated one. In the case of *G. palpalis,* local elimination of the fly is possible by clearing away the undergrowth which provides the dense shade that it seems to require. Perhaps the most promising lines of investigation at present are the construction of artificial trap breeding-places, where pupæ can be regularly collected and destroyed, and the study of the effect of large-scale clearing and grass-burning operations on the distribution of the flies. But, in general, the control of *Glossina* is a problem that has not yet been satisfactorily solved.

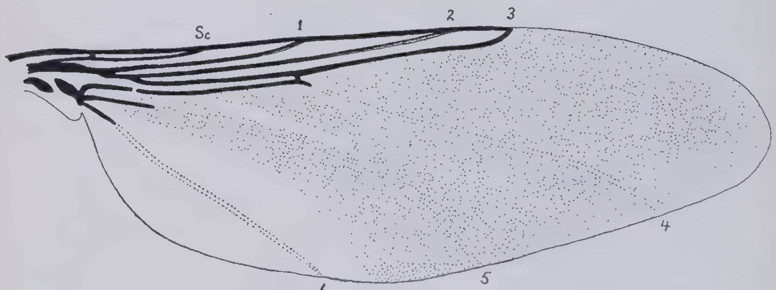


FIG. 253.—Wing of *Lynchia,* illustrating the type of wing venation found in the family Hippoboscidæ. (Original. Root)

IV. *Section Pupipara—Especially the Family Hippoboscidæ*

The flies of this section are practically all ectoparasitic, in the adult stage, on birds and mammals. Two families (STREBLIDÆ and NYCTERIBIIDÆ) are exclusively parasitic on bats.

The "tick-flies" or "louse-flies" included in the family HIPPOBOSCIDÆ are parasitic on mammals and birds and have much the

same method of reproduction as *Glossina*, producing only one larva at a time, and retaining it within the body of the female fly until it is ready to pupate. These flies rarely attack man and are of medical interest only because some of them act as vectors of blood-inhabiting protozoa which are related to those causing human diseases. A key to the genera of HIPPOBOSCIDÆ has been published by Aldrich (1923).

Some of the more common genera and species are noted below.

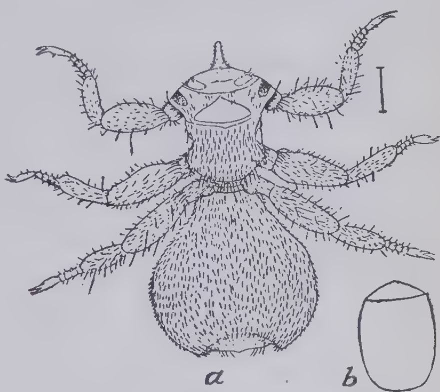


FIG. 254.—*Melophagus ovinus*. *a*, adult; *b*, puparium. (After Osborn)

Genus Hippobosca. Includes a number of Old World species with well-developed wings, all parasitic on mammals except *H. struthionis*, which is found on the ostrich. *H. equina* occurs on horses. *H. capensis* on dogs, *H. maculata* and *H. rufipes* on cattle, *H. camelina* on camels. Theiler (1903) showed that *H. rufipes* and *H. maculata* could transmit the non-pathogenic *Trypanosoma theileri* of cattle.

Genus Lipoptena. The species are parasitic on deer. Originally they have well-developed and functional wings, which are broken off near the body after they reach their hosts.

Genus Melophagus (Figure 254). Entirely wingless forms, parasitic on sheep, etc. The common "sheep-tick" or "ked" (*Melophagus ovinus*) is the vector of a non-pathogenic trypanosome of sheep.

Genus Lynchia (Figure 253). The winged *Lynchia maura* and its varieties are found on nestling pigeons in the tropics and subtropics. It is the vector of "pigeon malaria," caused by *Hæmoproteus columbæ*. It is suspected that the numerous Halteridial parasites of wild birds which have been described by various authors are also carried by the various Hippoboscid flies which are parasitic on birds.

CHAPTER XLVI

DOMESTIC FLIES AS DISEASE-CARRIERS AND THEIR CONTROL

I. *Domestic Flies*

The domestic flies, particularly the common house-fly, *Musca domestica* Linn., are often accused of carrying the causative organisms of intestinal diseases, such as typhoid fever, Asiatic cholera and dysentery, from human feces to human food. It is very difficult to determine how important such carriage is, although the possibility of its occurrence is undoubted.

In the case of typhoid fever, for example, the causative bacilli occur in the feces of typhoid patients or carriers. In order to have new cases of the disease these bacilli must reach human food or drink and be swallowed by non-immune individuals. Most large epidemics of typhoid fever can be traced back to a polluted water or milk supply. In such cases, evidently, flies do not play an important rôle. Small outbreaks of typhoid fever can often be connected with the presence of a typhoid carrier. If the region is well sanitated and the carrier is a food-handler, it seems obvious that the disease has been spread by direct contamination of food. If sanitary conditions are not good, however, and no typhoid-carriers can be found among those in charge of the preparation of food, the fly-transmission theory becomes more probable. In the army camps during the Boer War and the Spanish-American War, when large bodies of men were assembled under poor sanitary conditions, it seems probable that flies had a considerable part in the carriage of typhoid fever.

The flies which may be of importance in such transmission of intestinal diseases are evidently those domestic species which feed extensively and indiscriminately on both human fecal material and human food. Their breeding-places are probably of little importance. The internal changes which take place during the pupal stage are so extensive that it is very unlikely that bacteria or other disease-producing organisms taken up by the larva could be passed on to the

adult fly. So such flies as the green-bottles (genus *Lucilia*) which breed in decaying meat, are probably just as dangerous in proportion to their numbers as is the house-fly (*Musca domestica*) which often breeds in human fecal material, since both of them, in the adult stage, visit both excrement and food materials for feeding purposes. Conversely, such flies as *Morellia micans* and certain species of *Sarcophaga,* which often breed in human excrement in large numbers, are of practically no importance, since they are rarely, if ever, found in houses or around human food.

From this viewpoint, the domestic species of *Musca* (which in America means the species *Musca domestica*) are by far the most dangerous forms, since they are the most abundant flies in kitchens and dining-rooms and are also very numerous about fecal matter. Other flies which have somewhat the same habits and are also dangerous when present in houses and about food include the non-biting stable-fly (*Muscina*) the lesser house-flies (*Fannia,* family ANTHOMYIDÆ), certain of the flesh-flies (*Sarcophaga*) and a number of genera of the blow-flies (CALLIPHORIDÆ), particularly *Calliphora, Lucilia, Cochliomyia* and *Chrysomyia.*

The main diseases which these flies are accused of carrying include typhoid and paratyphoid fevers, cholera, dysentery (both bacillary and amœbic) and summer diarrhea. There have been a good many records of finding the eggs of various Helminth parasites of man in the alimentary canal or fecal droplets of flies, but such findings are of little importance. The eggs of most human Helminths must undergo a definite period of development outside the human body before they become infective, and the chance of their being deposited by the fly in a favorable environment for this development is extremely small. Flies might perhaps, however, function in the transmission of two Helminth parasites; one of these, *Hymenolepis nana,* utilizes the same individual as both intermediate and final host; the other, *Tænia echinococcus,* has the dog as its final host and may utilize man as an intermediate host.

Flies are also believed to play a part in the transmission of certain diseases whose causative organisms occur in discharges from the eyes or from open sores and wounds. The domestic species of *Musca* feed readily on such discharges and have been suspected of carrying ophthalmia in Egypt and Greece, and Yaws (caused by *Treponema pertenue*) in the tropics. In Panama, Darling (1911) proved that a disease of horses and mules caused by *Trypanosoma hippicum* was being transmitted by *Musca domestica* in this manner.

II. *The Control of Domestic Flies*

In attempting to control the domestic flies, especially the house-fly, two points should be kept in mind. In the first place, it is much easier and better to eliminate the breeding-places or kill the larvæ than to attack the fly in its adult stage. Second, the domestic flies seem to have an innate tendency to wander about. At Miles City, Montana, Parker (1916) released over 300,000 marked flies and captured some of them two miles away a day later. In Texas, Bishopp and Laake (1921) released 60,000 marked flies and caught one thirteen miles away after a few days. So fly control must be a community measure, not an individual matter. An individual can protect his house from flies fairly effectually by careful screening or continual trapping of adults, but in order to really get rid of flies the whole community must coöperate. A single neglected manure pile can produce flies enough for a whole village.

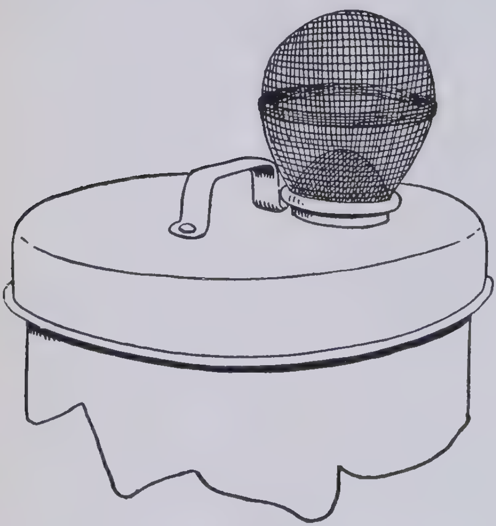


FIG. 255.—Top of garbage-can with small balloon fly-trap attached. (After Bishopp)

The favorite breeding-place of the house-fly is fresh horse manure, but it will also breed in excrement of almost any animals except cattle, and in garbage or decaying vegetable matter. The blow-flies breed mainly in decaying meat, either in garbage or in dead carcasses. To eliminate fly breeding-places, all such material should be buried, burned, enclosed or screened in such a way that flies cannot get at it to lay their eggs. Manure may also be rendered useless as a breeding-place for flies if it is spread on fields in a thin layer, so that it dries out quickly. If manure or garbage is removed periodically, it must be remembered that although, even in hot weather, it usually takes at least ten to twelve days for the fly to develop from egg to adult, the larva may reach the migratory stage and leave its breeding place in five or six days.

Many ingenious schemes have been devised to kill fly larvæ in manure before they are able to pupate. The most obvious measure, the use of chemicals which will kill the larvæ, is not very satisfactory, most chemicals either injuring the fertilizing properties of the manure or else being too expensive for large-scale use. The United States Department of Agriculture recommends the use of 0.62 pound of borax or 0.75 pound crude calcium borate to each eight bushels of manure. In China, Woodworth (1924) has reported success in

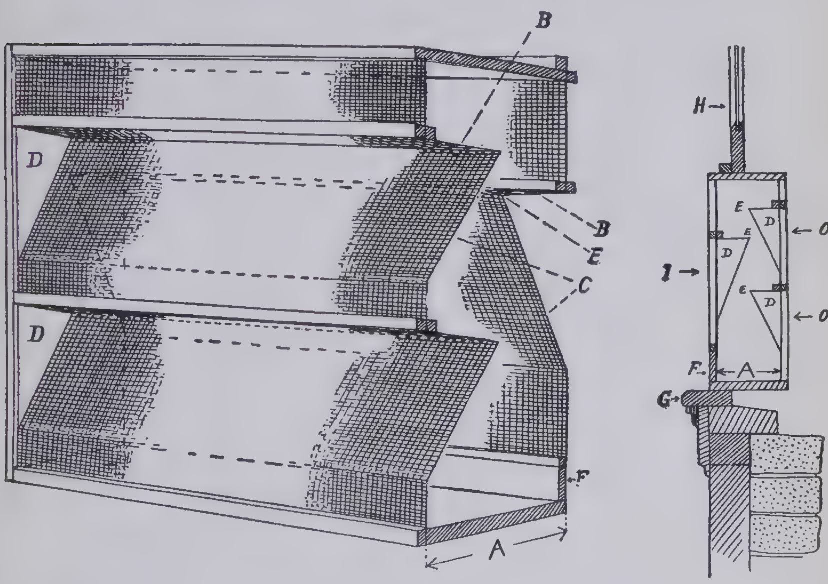


FIG. 256.—Hodge type window fly-trap. At left, trap with one end removed to show construction; at right, cross-section of trap in place in a window. (After Bishopp)

using sodium cyanide solution to kill fly larvæ in the "kongs" in which human manure is stored.

Several different "maggot traps" have been developed to catch and kill the larvæ during the migratory period. The manure is stored on an elevated platform or bin with a perforated floor and kept moist enough so that the larvæ will not pupate in it. They migrate downward when full-fed, pass through the perforated floor and drop into a concrete basin filled with water, where they drown. Other sanitarians have taken advantage of the fact that the heat of fermentation in a large manure pile is sufficient to kill any larvæ in its interior. Patton (1920) has adopted the plan of digging a hole in the center

of the pile every day and shoveling into it all the superficial manure in which fly-breeding is going on. Others have suggested keeping in the heat of fermentation by packing a tight layer of earth over the manure pile or covering it with a tarpaulin.

Adult flies may be destroyed in large numbers by the use of fly-traps, sticky fly-paper and poison. The fly-traps (Figures 255 and 256) are of many different designs but all depend on the fact that although flies will crawl into a dark place in search of food or for the purpose of laying eggs, when they leave they always fly upward and toward the light and the fact that when flies alight on a window-screen or other surface they crawl upward rather than down. Sticky fly-paper may be used in the usual sheets. It is said, however, that hanging wires or spirals smeared with the sticky mixture are more effective. A sticky mixture of this sort may be prepared by heating twenty pounds of clear resin in five quarts of castor oil and stirring until a clear solution is obtained.

When flies are troublesome in houses, they can be destroyed by a crude sort of fumigation, using the fumes of burning insect-powder, or by spraying one of the commercial preparations such as "Flyosan" or "Dethol." They can also be poisoned by the use of a 2 per cent solution of formalin in milk or sweetened water. This should be kept slightly alkaline in reaction or it loses its attractiveness to flies. Screening and the use of "fly-swatters" are also useful. But all measures directed against the adult fly are only palliative and do not lead to effective control.

CHAPTER XLVII

MYIASIS AND THE IDENTIFICATION OF FLY LARVÆ

I. *Myiasis*

Myiasis is the name applied to the diseases or symptoms produced by fly larvæ when they live parasitically in the bodies of man and other mammals. Clinically, myiases may be classified, according to the part of the body invaded by the larvæ, into:

Cutaneous myiasis—when the larvæ live in or under the skin.

Intestinal myiasis—when the larvæ are in the stomach or intestine.

Cavity and wound myiases—when the larvæ invade natural (nasopharynx, frontal sinuses, vulva) or artificial (wounds) cavities in the body.

Perhaps another category, that of external myiasis, should be added in order to include the case of blood-sucking maggots.

Although the larvæ of a great variety of flies have been reported as living parasitically in the human body, especially in the intestinal tract, the flies whose larvæ are of real importance in human and veterinary medicine belong very largely to the families ŒSTRIDÆ, CALLIPHORIDÆ and SARCOPHAGIDÆ.

The degree of injury resulting from myiasis depends upon the location and number of the larvæ and also upon their feeding habits, which, in turn, seem to depend on their degree of adaptation to a parasitic existence. The larvæ of the ŒSTRIDÆ, all of which are parasitic, seem well adapted to the parasitic mode of life and do not cause the death or serious illness of their host unless they are present in unusual numbers or accidentally reach an unusual location. These larvæ apparently feed on exudations, serum, and the like, without any extensive destruction of the host tissues.

The larvæ of blow-flies (CALLIPHORIDÆ) and some flesh-flies (SARCOPHAGIDÆ), on the other hand, feed on and destroy the host tissues, and are evidently not well adapted to a parasitic existence. Only a few species have larvæ which are always parasitic. In most

of the forms, the larvæ normally live in decaying meat and are only found occasionally as parasites. In such cases, extensive tissue-destruction occurs, and serious injury or even death may easily supervene unless the larvæ are removed.

In most cases of intestinal myiasis in man, the larvæ concerned are those which normally feed on fecal matter or decaying vegetable matter. In the alimentary tract they feed on the waste food material instead of on the tissues and rarely produce recognizable symptoms. In most cases their presence is accidental, resulting from the careless eating or drinking habits of the individual concerned.

The following survey includes most of the important Myiasis-producing genera of flies.

I. FAMILY ŒSTRIDÆ

This family is a rather heterogeneous assemblage of genera, almost certainly of multiple origin, but until we know more about the relationships of the different forms it does not seem worth while to break it up. All the genera agree in having larvæ which can only live as parasites of mammals, and in having the mouth parts of the adult flies more or less reduced and rudimentary. The larvæ are found, for the most part, in three locations in their hosts, the stomach, the nasal passages or the skin. They are usually found in wild or domestic animals and only occasionally and accidentally in man.

Genera whose larvæ occur in the stomach. This group includes the common "stomach-bots" of horses. (*Gasterophilus*) and related forms from the rhinoceros (*Gyrostigma*) and elephant (*Cobboldia*). In *Gasterophilus* the eggs are laid attached to hairs on the horse. They hatch under the influence of friction and moisture when the horse is licking its own body or that of another horse and the larvæ cling to the tongue and are swallowed. They attach themselves to the stomach-wall and remain attached until full-grown, when they pass out with the excrement and pupate in the earth.

Genera whose larvæ occur in the nasal passages. This group includes a considerable number of genera. The best known are *Œstrus* from sheep and various antelopes and *Rhinœstrus*, species of which occur in horses, in the African river-hog and in the hippopotamus. Representatives of other genera are found in various African antelopes (*Kirkiœstrus, Gedœlstia*) camels (*Cephalopsis*) and deer (*Cephenomyia*). In *Œstrus* and *Rhinœstrus* the female flies deposit newly hatched larvæ in the nose of the host. The larvæ work their

way into the sinuses where they become attached to the mucous membrane. When fully grown they make their way out of the nostrils and drop to the ground to pupate.

Genera whose larvæ occur in the skin. This group includes the "warbles" of cattle. (*Hypoderma*) and of the reindeer (*Œdamagena*), the "gusano del monte" of tropical America (*Dermatobia*), which occurs normally in cattle and not infrequently in man, and several genera (especially *Cuterebra* and *Bogeria*), whose larvæ usually occur in rodents and other small mammals. In *Hypoderma,* the eggs are laid on the skins of cattle, attached to the hairs. When the larvæ hatch it is thought that they burrow into the skin and migrate through the body for some time, later appearing on the back, where they produce subcutaneous swellings. When full-grown they emerge through a small opening which they have made in the skin and drop to the ground to pupate.

Except in the case of *Dermatobia,* human cases of myiasis due to Œstrid larvæ are comparatively rare. Cases in which young larvæ of *Hypoderma* and *Gasterophilus* have been found migrating under the skin of human beings, producing one form of "creeping eruption," have been reported. In some parts of Europe females of *Rhinœstrus purpureus* Brauer occasionally deposit their larvæ in the nose or eyes of human beings. *Œstrus ovis* Linn. is said to have the same habit in some parts of the world. The presence of these larvæ in the eyes produces severe conjunctivitis and may cause the loss of sight if the larvæ are not promptly removed.

In tropical America, larvæ of *Dermatobia hominis* Linn. are not infrequently found in the skin of human beings, although they are much more abundant in cattle. The occurrence of these larvæ in their normal location in an unusual host is bound up with the extremely interesting mode of oviposition of this species. Instead of laying her eggs on the body of the host of the larvæ, the female *Dermatobia* catches mosquitoes and other flies which visit cattle and lays her eggs in two packets on the sides of the abdomens of her captives. In Central America and northern South America, *Dermatobia* eggs are found almost exclusively on the mosquitoes, *Psorophora lutzii* and *Psorophora ferox,* but in Brazil they have been found both on these mosquitoes and also on the biting flies, *Stomoxys* and *Hæmatobia,* and even on non-biting flies such as *Musca domestica.* When the larvæ are ready to hatch from the egg, the body heat of a warm-blooded animal seems to stimulate them to leave the egg-shell and crawl onto the skin while their vector is feeding. They then burrow

into the skin and form a swelling similar to those produced by *Hypoderma* larvæ. When full-grown they emerge and drop to the ground to pupate.

2. FAMILY CALLIPHORIDÆ

To this family are now assigned certain genera (*Cordylobia* and *Bengalia*) which may represent a transition leading to the Œstrid type. Their larvæ closely resemble those of the ŒSTRIDÆ in structure and parasite mode of life, but the adult flies are still of Calliphorid structure. These flies occur only in Africa, and although their normal hosts are probably dogs, cats, and other wild and domestic animals, their larvæ have often been found in man. It is said that these flies lay their eggs on the ground where their hosts frequently lie down or sometimes on clothing or even on the bodies of man and animals, the larvæ burrowing into the skin when they hatch.

In Africa, also, is found the only blood-sucking maggot which attacks man. The larvæ of *Auchmeromyia luteola* Fabr., often called the "Congo floor-maggots," live in the dirt floors of native huts, coming out at night like bedbugs to suck the blood of sleepers. In Europe and America the larvæ of *Protocalliphora* feed in the same way on the blood of nestling birds.

The more typical members of the family CALLIPHORIDÆ are the various blow-flies, whose larvæ, as a rule, live in decaying meat. But the larvæ of many different blow-flies are occasionally found in the neglected wounds of man and animals; there are some species whose larvæ very frequently occur in such situations; and a very few in which the parasitic habit of life has become essential. Myiases caused by these larvæ are more dangerous to man than any other type and are also very important in connection with domestic animals, particularly cattle, horses and sheep, because of the extensive tissue destruction which results. Larvæ of *Calliphora, Cynomyia, Lucilia, Phormia* and some species of *Chrysomyia* are occasionally found in wounds, in the soiled wool of sheep, and so on. "Screw-worms," the larvæ of *Cochliomyia macellaria* Linn., frequently infest the wounds of animals and sometimes the nose of human beings in tropical and sub-tropical America. This fly will still breed in decaying meat, but the larvæ are frequently parasitic. According to Patton (1920) the larvæ of *Chrysomyia bezziana* are only found in the bodies of animals and man, and he considers this species to be the most important myiasis-producing fly in India. It is known to be common in Africa also.

3. FAMILY SARCOPHAGIDÆ

Many species of the genus *Sarcophaga* breed in decaying meat and are occasionally found infesting neglected wounds of man or animals. The species of the genus *Wohlfahrtia,* on the other hand, appear to breed only in living animals. *Wohlfahrtia magnifica* Schiner has been found breeding in wounds of animals and the nose, ears and skin of man, in Europe and Africa. In America *Wohlfahrtia vigil* Walker and *W. meigeni* Schiner have been bred from larvæ in the skin of infants and in rabbits.

There are other species of *Sarcophaga* which breed mainly or entirely in fecal material, frequently in human excrement. Most of the cases in which *Sarcophaga* larvæ from the intestinal tract of man have been bred out have given *S. hæmorrhoidalis,* which breeds in fecal matter. Such cases have usually been attributed to the deposition of larvæ by the flies on exposed food-substances, but the fact that the species most frequently found is a fecal-breeder suggests that the larvæ may have been deposited near the anus during visits to open toilets.

4. OTHER FAMILIES

The larvæ of many other flies of several different families are occasionally reported as parasitizing man, especially in the intestine. *Eristalis* (SYRPHIDÆ), *Musca, Muscina* and *Stomoxys* (MUSCIDÆ), *Fannia* (ANTHOMYIDÆ), *Piophila* (SEPSIDÆ), and *Aphiochæta* (PHORIDÆ) have all been encountered a number of times in the intestinal tract. Larvæ of *Fannia* have also been found on several occasions in the urogenital organs.

II. *Identification of Fly Larvæ*

The identification of first and second stage larvæ of the muscoid flies is a matter of considerable difficulty, in most cases. This is in part because the young larvæ do not have such easily recognizable characteristics as the mature larvæ and in part because the young larvæ have not been sufficiently studied. The paper by Miss Tao (1927) and the references given in it may be consulted. In the third stage or mature larvæ, the most important structures can usually be made out fairly well if living or preserved larvæ are examined with the binocular microscope, although the details can be seen much better if a small portion of the integument, including the spiracles, is cut off, treated with caustic potash and mounted in balsam for examina-

tion with the compound microscope. In some larvæ, so much chitin is deposited in the posterior spiracles just before pupation that they must be bleached before the structure can be made out clearly.

Each of the posterior spiracles usually consists of three parts (compare Figure 258). Surrounding the whole spiracle there is often a complete or almost complete chitinous *ring*. Within this are the *slits,* the actual apertures by which air enters the body of the larvæ. Typically there are three straight or sinuous slits, each divided up into a number of smaller apertures by a series of chitinous bars. In a number of Œstrid larvæ, we find a large number of small round, oval or sinuous apertures scattered over the entire surface of the spiracle, instead of the usual three large slits. Usually there can also be seen a small round chitinized area, often perforated, which is called the *button.* In larvæ of the MUSCIDÆ (Figure 258: 7-11) the

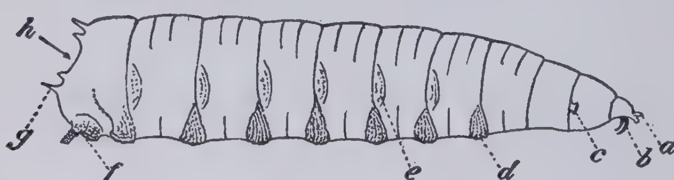


FIG. 257.—Mature larva of a Muscoid fly. *a,* head papillæ; *b,* mouth hooks; *c,* anterior spiracles; *d,* ventral spinose area; *e,* lateral spinose area; *f,* anal tubercle; *g,* tubercle on rim of stigmal field; *h,* position of stigmal field. (After Banks)

button usually lies inside the ring and is attached to it. In the CALLIPHORIDÆ, some genera (*Calliphora,* for example) have the button forming part of the ring (Figure 258: 1-3), while others (*Cochliomyia, Phormia*) have the button area very slightly chitinized, so that the ring is broken at that point (Figure 258: 4-5) This condition is also found in larvæ of *Sarcophaga.*

Other features of value in identifying fly larvæ are the general shape of the body and especially the form of the posterior end, which may be abruptly truncate (*Morellia*), rounded (*Musca*), with the stigmal field slightly depressed and surrounded by a tuberculate ridge (CALLIPHORIDÆ), with the spiracles situated in a definite pit (SARCOPHAGIDÆ) or even in a closed pocket (certain ŒSTRIDÆ). The number of branches or apertures of the *anterior spiracles* varies considerably in any species, but is sometimes of value. The structure of the *cephalopharyngeal sclerites* within the head and anterior segments of the larvæ also show some very characteristic modifications in different larvæ, but these structures have not been thoroughly studied as yet. The following key is by no means complete and has

FIG. 258.—Posterior spiracles of third-stage larvæ of some common genera of Muscoid flies. 1, *Calliphora erythrocephala;* 2, *Cynomyia cadaverina;* 3, *Lucilia sericata;* 4, *Phormia regina;* 5, *Cochliomyia macellaria;* 6, *Sarcophaga bullata;* 7, *Stomoxys calcitrans;* 8, *Musca domestica;* 9, *Cryptolucilia cornicina;* 10, *Morellia micans;* 11, *Muscina stabulans.* (Original. Root)

not been carried beyond referring the larvæ to certain groups of genera, but may be found to be useful.

KEY TO THIRD-STAGE LARVÆ OF SOME OF THE MUSCOID FLIES

1. Larvæ of the normal muscoid shape, i.e., slender, cylindrical, tapering anteriorly, more or less truncate posteriorly, without lateral or posterior processes 2
   Larvæ either large, stout and more or less flattened dorsoventrally or else with lateral or posterior processes 7
2. Posterior spiracles with button area well chitinized and ring complete 3
   Posterior spiracles with button area very slightly chitinized and ring incomplete 6
3. Button area a part of the ring; slits nearly straight ....*Calliphora, Lucilia, Anastellorhina, Neopollenia.*
   Button area within ring 4
4. Slits only slightly bent ....*Muscina.*
   Slits sinuous, much curved 5
5. Posterior spiracle D-shaped; each slit thrown into several loops *Musca, Philæmatomyia, Hæmatobia, Cryptolucilia, Morellia,* etc. ....
   Posterior spiracle triangular with rounded corners; each slit S-shaped ....*Stomoxys, Bdellolarynx, Hæmatobosca.*
6. Inner slits sloping downward and outward; middle slits nearly vertical; outer slits sloping downward and inward ....*Sarcophaga, Wohlfahrtia,* etc.
   All of the slits sloping downward and inward ....*Cochliomyia, Chrysomyia, Phormia, Protophormia.*
7. Larvæ large, stout, more or less flattened dorso-ventrally, usually without processes ....ŒSTRIDÆ 9
   Larvæ short, stout, cylindrical, with a very long, tubular process posteriorly ....*Eristalis* (SYRPHIDÆ).
   Larvæ with fleshy or spinose lateral processes 8
8. Posterior spiracles placed in a depressed stigmal field ....*Chrysomyia albiceps, varipes* and *villeneuvii.*
   Posterior spiracles elevated on short tubercles..........*Fannia.*
9. Posterior spiracles each with three distinct slits 10
   Posterior spiracles each with a large number of small apertures. 13
10. Slits of posterior spiracles nearly straight .... *Dermatobia, Cobboldia.*
   Slits of posterior spiracles decidedly curved or sinuous 11
11. Each slit bent at its middle ....*Gasterophilus.*
   Each slit thrown into several loops 12
12. Slits separate from each other and not parallel to each other .... *Cordylobia* (CALLIPHORIDÆ).
   Slits close together and parallel to each other......*Gyrostigma.*
13. Each posterior spiracle a single solid plate; its apertures without obvious cross-bars 14

Each posterior spiracle more or less distinctly divided into several plates; its apertures small, curved, cross-barred slits .... *Cuterebra.*

14. Button area a part of the spiracular plate ....*Œstrus, Rhinœstrus, Gedœlstia,* etc.

Button area separate, lying in an indentation of the spiracular plate 15

15. Button area strongly chitinized, lying in a deep indentation of the spiracular plate ....*Hypoderma.*

Button area weakly chitinized, lying in a shallow indentation .... *Cephalopsis.*

CHAPTER XLVIII

ORDER SIPHONAPTERA—FLEAS

I. *Characteristics*

Fleas may be readily recognized as such by their complete lack of wings, their compressed or laterally flattened form and their remarkable jumping ability. Their life history includes a complete metamorphosis, with egg, larval, pupal and adult stages. The adult fleas are ectoparasites of birds and mammals and feed only on blood, although they may spend considerable time in the nest or burrow of their host instead of on its body. As a rule, each species of flea infests a particular host species or group of species, but fleas are more apt to straggle onto unusual hosts than lice, for example, because of their greater motility. The larvæ of fleas are not really parasites, although they usually live in the nest of the host of the adult stage.

II. *Structure of Adult Flea*

On the sides of the head there may be a pair of *ocelli* or simple eyes. These are vestigial or absent in some fleas. Just behind the eyes are a pair of *antennal grooves,* in which the antennæ lie when at rest. The antennal grooves divide the head, more or less completely, into an anterior *frons* and a posterior *occiput*. The ventral edge of the *frons* is called the *gena* and bears a *genal comb* of stout spines in some species. The antennæ are much like those of the Tabanidæ, consisting of three segments of which the terminal one or *club* is more or less completely divided into about nine smaller divisions. The mouthparts project ventrally or ventro-anteriorly from the lower anterior corner of the head. The *maxillæ* and the *labium* are both short and reduced, but bear prominent, jointed *maxillary* and *labial palpi*. The piercing organs are the two *mandibles,* with serrated edges. There is also a slender rod-like *epipharynx*. In use, the mandibles and epipharynx lock together, forming a food canal and a salivary duct.

Since wings are entirely absent and each of the three thoracic segments bears a pair of legs, they are all of about the same size and of comparatively simple structure, each consisting of a dorsal

tergite and a ventral *sternite*. The sternites of the mesothorax and metathorax bear internal rod-like thickenings (Figure 259) which mark out the limits of areas which are called *episternum, epimeron* and *sternum*. The *epimeron* of the metathorax is large and overlaps the abdomen, taking the place of the sternite of the first abdominal segment. The tergite of the prothorax may bear a *pronotal* comb of spines similar to that on the gena.

The legs are strong, particularly the hind pair which is used for jumping. Each leg is made up of coxa, trochanter, femur, tibia and

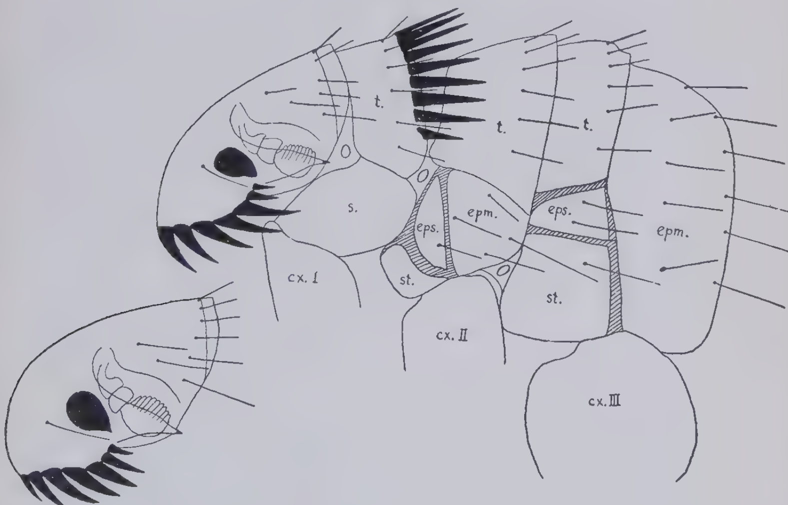


Fig. 259.—Head and thorax of female *Ctenocephalus felis*, with head of female *Ctenocephalus canis* below, for comparison. t., tergites of the thoracic segments; s., sternite of the prothorax; st., sternites of mesothorax and metathorax; eps., episternum; epm., epimeron; cx.I, cx.II, cx.III, coxæ of first, second and third legs. (Original. Root)

five tarsal segments. The last tarsal segment bears a pair of long claws. The arrangement of the spines and bristles on the various segments of the legs is often of importance in distinguishing genera and species.

The abdomen consists of ten segments, of which the last two are considerably modified for sexual purposes. Each segment has a dorsal *tergite* and a ventral *sternite*. Both tergite and sternite usually have one or more rows of backwardly pointing bristles. Dorsally, near its posterior margin, the seventh tergite bears a pair of very strong *antepygidial bristles*. Just posterior to these bristles is a hairy pad, probably sensory in function, known as the *pygidium*. In male fleas

the abdomen ends with the hypopygium or clasping apparatus, and in cleared specimens a complicated internal genital apparatus may also be seen. In female fleas the external genitalia are less complex and all that can be seen of the internal structures in specimens treated with caustic potash is the chitinized *spermatheca* or *seminal receptacle.* The details of form of the male hypopygial structures and of the female seminal receptacle are often of great importance in identifying fleas (see Fox, 1914).

III. *Life History of Fleas*

The female flea lays her small oval or elongate eggs either in the nest of the host or among its hairs or feathers. In the latter case they are not attached to the host and drop off before hatching. The larva (Figure 260) is a slender, legless, worm-like organism with a distinct head, looking not unlike the larvæ of some of the DIPTERA NEMATOCERA. Flea larvæ feed on any nourishing particles in the debris in which they live, particularly on the fecal pellets of the adult fleas. After moulting or changing its skin three times the larva is mature and spins a thin silken cocoon, attached to the surrounding dust or debris. Within this pupation occurs. Usually, in any brood of flea larvæ, some will pupate at once after making their cocoons, while others will lie quiescent within the cocoon for a longer or shorter time before pupating. This ensures that the fleas proceeding from a single batch of eggs do not all emerge at once but come out from their cocoons at intervals over a considerable period of time. This would make it more likely that some of the fleas would find a host available when they hatched out, in the case of wandering or migratory hosts. The length of the entire life history may be as short as four weeks for some individuals in hot climates, but may be much longer, even in other individuals of the same brood.

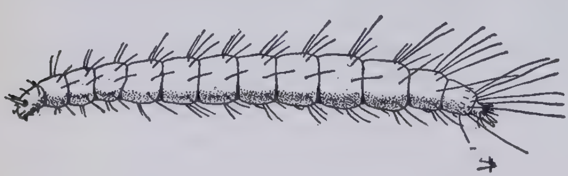


FIG. 260.—Mature larva of flea. (After Bishopp)

IV. *Classification*

The order SIPHONAPTERA is divided into two suborders, the FRACTICIPITA, in which the antennal grooves divide the head com-

pletely and the frons and occiput are capable of independent movement, and the INTEGRICIPITA, in which the frons and occiput are fused together dorsally, the division of the head by the antennal grooves being incomplete. Each of these suborders is further divided into a number of families, of which the most important to us are, in the FRACTICIPITA, the Family LEPTOPSYLLIDÆ and in the INTEGRICIPITA, the Families TUNGIDÆ, PULICIDÆ and CERATOPHYLLIDÆ.

A complete key to the genera of fleas of the world will be found in Fox (1925). From the medical viewpoint, the fleas of interest to us are those which are commonly found on rats and other rodents which are subject to bubonic plague, and those which may attack man or form a pest in houses. The following simple key includes only those genera which come under these categories.

KEY TO THE GENERA OF SIPHONAPTERA WHICH ARE OF MEDICAL IMPORTANCE

1. The three thoracic tergites together shorter than the first abdominal tergite 2
   The three thoracic tergites together longer than the first abdominal tergite 3
2. Hind coxa with a patch of small spinules on its inner side .... *Echidnophaga.*
   Hind coxa without a patch of spinules internally.......... *Tunga.*
3. Eyes well-developed 4
   Eyes vestigial or absent; both pronotal and genal combs present. 9
4. Neither pronotal nor genal combs present 5
   Pronotal comb, at least, present 6
5. Mesosternite with only one internal rod-like thickening, which extends from the insertion of the coxa forward to the anterior border .... *Pulex.*
   Mesosternite with two internal rod-like thickenings, one extending forward and the other upward .... *Xenopsylla.*
6. Both pronotal and genal combs present 7
   Pronotal comb present but genal comb absent 8
7. Genal comb running horizontally along lower border of gena .... *Ctenocephalus.*
   Genal comb running obliquely across gena.......... *Spilopsyllus.*
8. Third segment of antenna distinctly segmented both anteriorly and posteriorly .... *Ceratophyllus.*
   Third segment of antenna distinctly segmented only on the posterior side .... *Hoplopsyllus.*
9. Posterior edge of tibiæ with about eight short and several long bristles, which do not resemble a comb.......... *Ctenophthalmus.*
   Posterior edge of tibiæ with about twelve short and three long bristles, the short ones forming a sort of comb.... *Leptopsylla.*

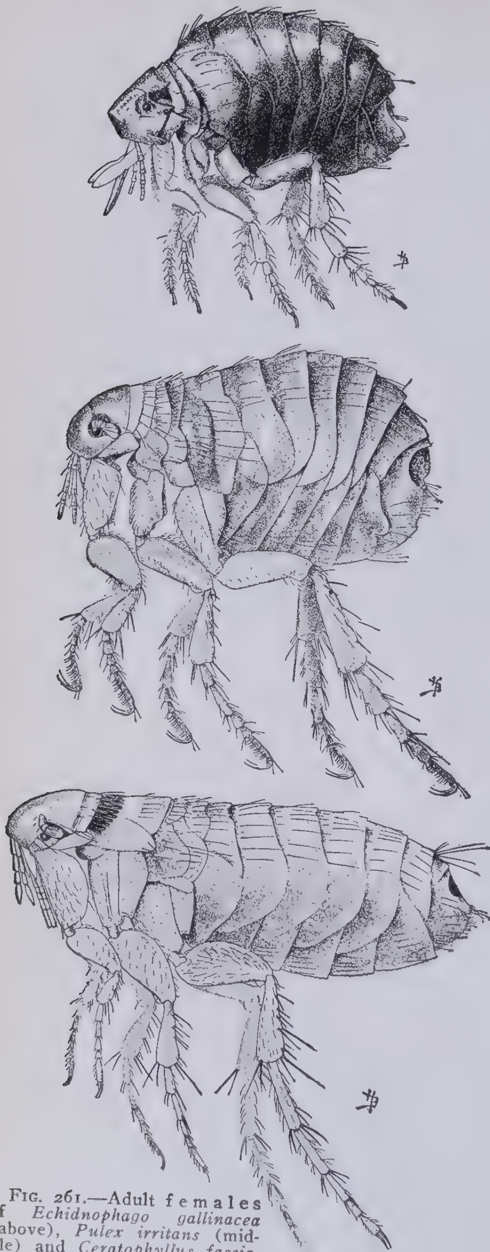


FIG. 261.—Adult females of *Echidnophago gallinacea* (above), *Pulex irritans* (middle) and *Ceratophyllus fasciatus* (below). (After Bishopp)

V. *Family Tungidæ*

The fleas belonging to this family are sometimes called the "burrowing fleas," because the pregnant female attaches herself firmly to the skin of her host, causing such irritation that the skin swells up around her, partly or completely closing her body.

Tunga penetrans Linn.: This is the "chigoe" of tropical America, which has also been introduced into Africa. The pregnant female attaches herself to the skin of man, dogs and pigs and becomes almost completely enclosed by the resultant swelling. Within this enclosure the abdomen of the flea swells up to the size of a pea because of the numerous eggs developed. The eggs pass out through a small aperture and drop to the ground. When all the eggs are laid the flea dies and the swelling in which she lived often becomes secondarily infected, sometimes with serious results. In man, the skin

of the foot, particularly between the toes, is the most usual site of infestation.

Echidnophaga gallinacea Westwood (Figure 261): the "stick-tight flea" of chickens, which usually attaches itself about the head of chickens and other birds, is also frequently found on rats, dogs and cats and sometimes on man. It was probably originally an inhabitant of Asia, but is now found throughout the tropical and subtropical regions of the world.

VI. *Family Pulicidæ*

Pulex irritans Linn. (Figure 261): this species is usually referred to as the "human flea," and is the species most frequently found in houses and on human beings in most parts of the world. In the eastern and southern United States, curiously enough, flea infestation of houses is almost invariably due to dog and cat fleas, although the "human flea" is sometimes found in these regions in enormous numbers on hogs. It sometimes occurs on rats and other small mammals.

Xenopsylla: this genus includes a great many species, mainly Old World forms infesting various rodents. Three species are commonly found on rats. They may be differentiated by the differences in the male hypopygia and female seminal receptacles shown in Figure 262.

Xenopsylla cheopis Rothschild: this is the Indian rat flea, and probably of more importance than any other species in the transmission of bubonic plague. It is now the most abundant rat flea in nearly all parts of the tropics and subtropics, and is frequently encountered in ports which are in the temperate zone but have considerable trade with tropical countries. Although its original host was probably the black rat (*Rattus rattus*), it is also found on the brown rat (*Rattus norvegicus*) and readily attacks man and many other mammals.

Xenopsylla astia Rothschild: this rat flea is only found in the Orient. It has recently been shown (Cragg, 1921, 1923) that in regions where *X. astia* is the predominant rat flea, epidemics of Bubonic Plague are rare or absent.

Xenopsylla brasiliensis Baker: this rat flea occurs in India, Africa and South America. It is not known whether it is a good carrier of plague or not.

Ctenocephalus: this genus includes the dog flea (*Ct. canis* Curtis) and the cat flea (*Ct. felis* Bouché), which resemble each other so closely that they have sometimes been considered varieties of a single species. The most obvious difference between them is the shape of

the head (Figure 259). These fleas are found mainly on dogs and cats, but often occur on man, rats and other mammals. They are the fleas usually found in house infestations in the eastern and southern United States. Besides being able to transmit bubonic

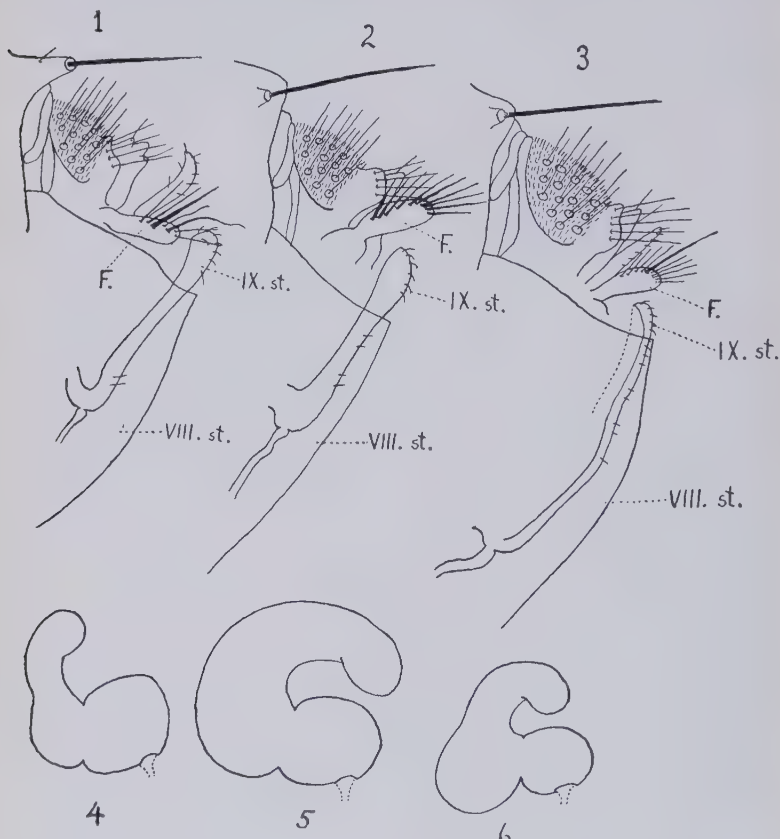


FIG. 262.—Differential characters of three species of *Xenopsylla*. 1, modified abdominal segments of male *X. brasiliensis;* 2, same of *X. cheopis;* 3, same of *X. astia;* 4, seminal receptacle of female *X. brasiliensis;* 5, same of *X. cheopis;* 6, same of *X. astia*. F., outer flap of clasper; VIII. st., and IX. st., eighth and ninth sternites. (Redrawn after Rothschild)

plague, these fleas may serve as intermediate hosts of the tapeworms *Dipylidium caninum* and *Hymenolopis diminuta,* and the dog flea has been suspected to be a vector of infantile kala-azar.

Spilopsyllus: this genus contains a number of rabbit fleas which

are not of medical importance, but are mentioned because of their resemblance to the dog and cat fleas.

Hoplopsyllus anomalus Baker: this species is one of the common fleas of the California ground-squirrel (*Citellus beecheyi*) and is of some importance as a vector of bubonic plague in regions where the infection is present in ground-squirrels.

VII. *Family Ceratophyllidæ*

Ceratophyllus: this genus includes a great variety of fleas, some of which are parasites of birds while others infest small mammals. Four species are believed to be of some importance in connection with the transmission of bubonic plague, but it is not worth while to attempt to give their specific characteristics.

Ceratophyllus fasciatus Bosc. (Figure 261): the common rat flea of Europe and North America. Probably originally the flea of the brown rat (*Rattus norvegicus*).

Ceratophyllus anisus Roth.: replaces *C. fasciatus* as the common rat flea of North China and Japan.

Ceratophyllus acutus Baker: a common flea of the California ground squirrel.

Ceratophyllus silantiewi Wagner: The flea of the Manchurian marmot or "tarbagan" (*Arctomys bobac*), which is sometimes infected with plague.

VIII. *Family Leptopsyllidæ*

Leptopsylla musculi Duges: this species is said to be the common flea of the house mouse (*Mus musculus*) in Europe. In America it is comparatively rare and occurs on rats rather than mice.

Ctenophthalmus agyrtes Heller: a common flea of field mice in Europe which is occasionally found on rats.

IX. *Fleas as Disease-Carriers*

Fleas are of interest to medical men mainly because of their connection with the transmission of bubonic plague from rats and other rodents to human beings. Bubonic plague is primarily a disease of rats, transmissible to ground-squirrels, marmots and other rodents and also, unfortunately, to human beings. While the pneumonic type of plague is transmitted from man to man by saliva droplets, and the like, bubonic plague is transmitted from rat to rat and

from rat to man by fleas and is almost never transmitted from man to man.

There are, apparently, two ways in which fleas may transmit bubonic plague. When the plague bacilli (*Bacillus pestis*) are taken into the stomach of the flea with its blood meal they undergo considerable multiplication there, but do not penetrate into other parts of the body, the salivary glands, for example, remaining free from them. Large numbers of plague bacilli pass out in the fecal droplets deposited by an infected flea and it is probable that human infections may result from rubbing these fecal droplets into the bite when it is scratched. Bacot and Martin (1914) have also shown that in some infected fleas the multiplication of the plague bacilli is so rapid that they actually obstruct the little spherical proventriculus to such an extent that little or no blood can pass into the stomach. Such fleas make violent efforts to feed, in the course of which some of the plague bacilli are mixed with the blood and regurgitated into the bite, thus bringing about infection. Experiments have proved that most species of fleas found on rats and other plague-infected rodents will readily bite human beings. Rarely, as in the case of the European field mouse flea, *Ctenophthalmus agyrtes*, it has been found impossible to induce a species to bite man, although it may become infected with plague bacilli by feeding on an infected rat. Such a flea can play a part in the transmission of plague from rat to rat, but would not be of any importance in transmitting plague to human beings.

Since bubonic plague is primarily a disease of rats and human beings are only infected by accident, so to speak, it is usual to find the disease already widely prevalent among the rat population when the first human cases are recognized.

To control the disease, it is necessary either to entirely prevent contact between rats (or rather their fleas) and human beings or else to eradicate the disease among the rats.

Rat-proof construction. The most valuable measure in keeping rat-fleas from coming in contact with man is the rat-proofing of all buildings and other structures where rats can obtain food and shelter. In dealing with the ordinary Brown Rat, reinforced concrete or cement construction in cellars, basements and ground floors is particularly necessary, since this species is a terrestrial, burrowing rodent which is rarely found in the upper portions of buildings. The black rat was originally an arboreal, climbing species, and may be found in the upper stories of even tall buildings. It is also often found on ships.

If plague among the rats is confined to a definite area, contact between rat fleas and man may be prevented by the temporary depopulation of that district while an intensive effort to destroy all the rats in it is being made.

Killing rats. When killing rats to combat plague, it is of the greatest importance that as many dead rats as possible be brought into the laboratory and examined, so that the degree of plague infection in the rat population and the location of the plague foci can be determined. Rats sent in for examination should have been first dipped in kerosene to kill their fleas and should always be labelled with the locality from which they came.

When a plague focus has been found, an intensive campaign of rat-killing and rat-proofing should be carried on all around it, in the attempt to isolate it and eradicate the disease within it.

In actually killing rats, the main reliance is placed on traps and poisons. But the older rats, particularly, are very wary, and before they can be successfully trapped or poisoned it is necessary to cut off their food supply, so that they will be desperate with hunger. This requires the placing of all garbage and refuse in rat-proof receptacles pending collection and incineration and the protection of stored food-stuffs and animal feeds from rats. Special attention must be given to the rat-proofing of stables, yards and wharves where carelessness may make food available for the rats.

Trapping is done either with snap-traps or cage-traps. The former are usually more effective, but a certain number of rats should be trapped alive in cage-traps to obtain data on the kind of fleas present and their numbers. In general the type of trap used is of much less importance than the skill and experience of the trapper in determining success.

The use of stomach poisons against rats is rather dangerous, since most of the poisons used, for example, arsenic, phosphorus and strychnine, are also fatal to human beings. The use of various bacterial viruses against rats is also of little value. In the case of ships, warehouses and buildings known or suspected to harbor infected rats, fumigation with hydrocyanic acid gas or some similar compound is very effective in destroying the rats, but must be cautiously done, since the gas is also poisonous to man.

When plague infection spreads from the city rats to wild rodents such as ground-squirrels, their destruction must be undertaken in much the same way. Ground-squirrels, for example, may be killed by shooting, trapping and the use of poison baits or by fumigating the burrows in which they live.

In anti-plague campaigns it is not usual to lay any particular stress on the control of fleas. When houses become heavily infested with fleas, however, it is necessary to take measures to eradicate them and prevent their reintroduction. To eradicate fleas and other insect pests in houses, fumigation with hydrocyanic acid gas is very effective, but so dangerous that it cannot always be attempted and then only by men thoroughly trained in its use. Simpler measures, which are often efficacious, are mopping the floors with kerosene, sprinkling them with powdered naphthalene or spraying floors, rugs and furniture with cresol compounds. These measures must be repeated several times at short intervals to insure success. In the eastern and southern United States, flea infestation of houses is practically always due to the multiplication of fleas from dogs or cats, and these pets should be regularly bathed with dilute creolin (3 per cent) or dusted with insect powder to keep them comparatively free of fleas. Their kennels or bedding should be burned weekly or treated with cresol solution to prevent flea breeding.

CHAPTER XLIX

ORDER ANOPLURA—LICE

The lice, like the fleas, are wingless, ectoparasitic insects. They differ decidedly from the fleas in two respects. First, their bodies are flattened dorsoventrally instead of laterally, and second, they are ectoparasitic throughout their entire life-cycle, even their eggs being firmly attached to the hairs or feathers of their hosts. The larval stages have exactly the same habit of life as the adults and resemble them closely in form, so that there is practically no metamorphosis in their life history.

The order ANOPLURA is now considered as including two suborders, the MALLOPHAGA (biting lice or "bird lice") and the SIPHUNCULATA (sucking lice or true lice).

I. *Mallophaga*

The "bird lice" have mouth parts of the chewing type, not unlike those of a grasshopper or beetle, and most of them, at least, are believed to feed on bits of dead skin, feathers or hair. The thorax shows a division into at least two distinct segments. The last of the two tarsal joints bears one or two claws, and only rarely is the tip of the tibia so formed that it is apposable to the claw. There are a great variety of species of MALLOPHAGA, most of which are ectoparasites of birds, but there are several genera which are ectoparasitic on mammals only. None of them attack man, so that they are of very little interest from the medical viewpoint. The following brief summary of their classification will be full enough for our needs.

Order ANOPLURA, Suborder MALLOPHAGA.
- Superfamily ISCHNOCERA (antennæ slender, three-jointed or five-jointed).
  - Family TRICHODECTIDÆ (antennæ three-jointed, feet with 1 claw, parasitic on mammals).
    - Genus *Trichodectes,* etc.
  - Family PHILOPTERIDÆ (antennæ five-jointed, feet with 2 claws, parasitic on birds).
    - Genera *Philopterus, Lipeurus, Goniodes, Degeeriella,* etc.

Superfamily AMBLYCERA (antennæ clubbed, four-jointed).
Family MENOPONIDÆ (feet with 2 claws, parasitic on birds).
Genera *Menopon, Colpocephalum, Trinoton,* etc.
Family BOOPIDÆ (feet with 2 claws, parasitic on mammals, especially marsupials).
Genera *Boopia, Trimenopon,* etc.
Family GYROPIDÆ (feet with 1 claw, parasitic on mammals).
Genera *Gyropus, Gliricola,* etc.

II. *Siphunculata*

The true lice have mouth parts of the sucking type, adapted to pierce the skin of their hosts and suck out blood. The three thoracic segments are fused together, without any clear dividing line between them. The single tarsal joint bears only one claw and in most species the tip of the tibia is widened and drawn out into a "thumb-like process" apposable to the claw. All of the true lice are ectoparasites of mammals, including man.

1. STRUCTURE OF THE SIPHUNCULATA

The head may or may not bear a pair of simple eyes or *ocelli.* The short *antennæ,* which may consist of from three to five joints are laterally placed, just in front of the eyes, if the latter are present. The oral opening is at the anterior end of the head, surrounded by a ring of *prestomal hooklets,* which grip the skin of the host firmly when the louse is feeding. From the oral opening can be protruded the piercing *proboscis,* which is made up of three slender stylets whose exact homologies are not well understood.

The thorax may show traces of segmentation, but is never completely segmented. A chitinous *sternal plate* may be present in the middle of the ventral surface. The middle thoracic segment has a pair of large *spiracles* or respiratory openings.

The legs are short and strong, with only one tarsal joint, as a rule. The tip of the tibia usually has a "thumb-like process," apposable to the single tarsal *claw.*

The abdomen usually shows nine segments, of which the first may be much reduced and the last two modified for sexual purposes. There are usually six pairs of abdominal spiracles, on segments 3-8 inclusive. Each of the abdominal segments has typically both a dorsal *tergite,* a ventral *sternite* and a pair of lateral *pleural plates.* The size and form of the pleural plates are often useful in identification.

2. CLASSIFICATION

The suborder SIPHUNCULATA is divided into four families. Two of these are of no particular interest to us, since the family ECHINOPTHIRIIDÆ includes only the lice infesting seals, sea-lions and walruses and the family HÆMATOMYZIDÆ contains the single genus *Hæmatomyzus,* parasitic on elephants. From the medical viewpoint the family of greatest importance is the PEDICULIDÆ, distinguished by the presence of well-pigmented eyes. It is divided into two subfamilies, of which the PEDICININÆ contains the lice of the Old World monkeys, while the PEDICULINÆ includes lice from lemurs, anthropoid apes, New World spider-monkeys and man. The family HÆMATOPINIDÆ is of importance to veterinarians, since it includes the great majority of the lice found on wild and domestic mammals. It includes several subfamilies, but the two main types of lice contained in the family are well typified by the large species of *Hæmatopinus* and *Linognathus,* usually found on Ungulates, and the smaller forms belonging to *Polyplax, Hœmodipsus,* and many other genera, which are parasitic on rodents and other small mammals.

The following condensed key includes all the genera of the PEDICULIDÆ and will also enable a student to get a general idea of the generic identity of the common lice of domestic animals.

To this is added a brief tabulation of the species of SIPHUNCULATA and MALLOPHAGA which are ordinarily encountered on the usual domestic and laboratory animals and birds. For further details regarding the lice encountered on wild mammals, see the papers by Kellogg and Ferris (1915) and by Ferris (1920, 1921, 1922, 1923).

KEY TO SOME OF THE GENERA OF THE SUBORDER SIPHUNCULATA

1. Body with spines or hairs in definite rows, never with scales... 2
   Body thickly covered with short stout spines or with spines and scales ....(Family *Echinopthiriidæ*).
2. Head not elongated; tibia with thumb-like process 3
   Head tubularly produced anteriorly; tibia without a thumb-like process ....(Family *Hœmatomyzidæ*).
3. Eyes rudimentary or absent ....(Family *Hœmatopinidæ*) 4
   Eyes present, usually well pigmented......(Family *Pediculidæ*) 8
4. Antennæ three-jointed....(EUHÆMATOPININÆ) *Euhœmatopinus.*
   Antennæ five-jointed 5
5. All legs and claws of the same size
   .... (HÆMATOPININÆ) *Hœmatopinus,* etc.
   Anterior legs and claws smaller than the posterior ones
   .... (LINOGNATHINÆ) 6

6. Abdomen entirely without pleural plates.......*Linognathus*, etc.
   Abdomen with well developed pleural plates.................. 7
7. Abdominal tergites and sternites mostly with only one transverse row of hairs or bristles.....*Hæmodipsus, Enderleinellus*, etc.
   Abdominal tergites and sternites mostly with more than one transverse row of hairs or bristles..*Polyplax, Hoplopleura*, etc.
8. Antennæ of adult three-jointed..................(PEDICININÆ) 9
   Antennæ of adult five-jointed ....(PEDICULINÆ) 10
9. Anterior legs smaller than middle and posterior pairs .... *Phthirpedicinus.*
   All legs of about same size ....*Pedicinus.*
10. Anterior legs smaller than middle and posterior pairs 11
    All legs of about same size ....*Pediculus.*
11. Abdomen long ....*Phthirpediculus.*
    Abdomen short and stout ....*Phthirus.*

Lice Commonly Encountered on Domestic and Laboratory Animals

Host	MALLOPHAGA	SIPHUNCULATA
Rhesus monkey	....	*Pedicinus rhesi* Fahr. *Phthirpedicinus micropilosus* Fahr.
Dog	*Trichodectes canis* DeGeer	*Linognathus setosus* Olfers
Cat	*Trichodectes subrostratus* Nitzsch	....
Horse	*Trichodectes equi* Linn. *Trichodectes pilosus* Giebel	*Hæmatopinus asini* Linn.
Pig	....	*Hæmatopinus suis* Linn.
Cow	*Trichodectes bovis* Linn.	*Hæmatopinus eurysternus* Nitzsch *Linognathus vituli* Linn.
Sheep	*Trichodectes ovis* Linn.	*Linognathus pedalis* Osborn
Goat	*Trichodectes caprae* Gurlt *Trichodectes hermsi* Kell. and Nak.	*Linognathus stenopsis* Burm.
Rabbit	....	*Hæmodipsus ventricosus* Denny
Guinea-pig	*Gyropus ovalis* Nitzsch *Gliricola porcelli* Schrank	....
Rat	....	*Polyplax spinulosa* Burm.
Chicken	*Menopon gallinæ* Linn. *Menopon stramineum* Nitzsch *Lipeurus heterographus* Nitzsch *Lipeurus caponis* Linn.	....
Turkey	*Goniodes meleagridis* Linn. *Lipeurus gallipavonis* Geoffroy	....
Duck	*Philopterus dentatus* Scopoli *Esthiopterum crassicorne* Scopoli	....
Pigeon	*Esthiopterum columbæ* Linn. *Goniocotes bidentatus* Scopoli	....

III. *Species of Lice Found on Man*

Human beings are parasitized by two species of lice, the pubic louse or crab louse (*Phthirus pubis* Linn. Figure 264) and the human louse (*Pediculus humanus* Linn. Figure 263). Authorities seem to agree that the latter species may be divided into two hybridizing subspecies, the head louse (*P. humanus humanus* Linn.) and the body louse or clothes louse (*P. humanis corporis* DeGeer.) Some students of the group believe that these two subspecies are characteristic of the Caucasian race, and that there are other subspecies of *P. humanus* which were originally confined to Negroes, Chinese, and American Indians respectively (see Ewing, 1926). They admit, however, that all forms of *P. humanus* interbreed and that many of the lice encountered in civilized lands are of hybrid type. Other authorities deny the existence of varieties of lice characteristic of the different races of mankind.

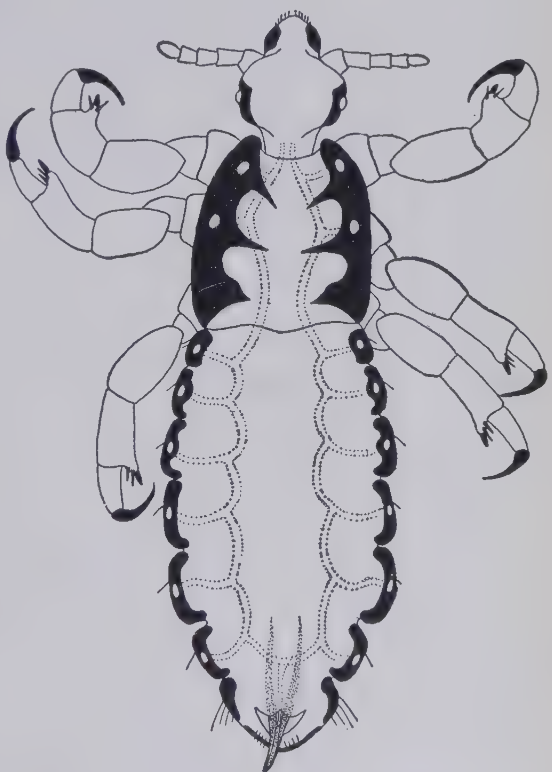


Fig. 263.—Male *Pediculus humanus*. (Original. Root)

The species and varieties of lice found on man differ somewhat in their habitats and habits. The head louse inhabits the head, attaching its eggs to the hair, while the body louse inhabits the clothing, usually attaching its eggs to the fibers of the cloth (Figure 265). The crab louse is usually found among the hairs of the pubic re-

gion, but in badly-infested individuals it may spread to the body and even to the head. It attaches its eggs to the hairs.

The eggs of lice hatch in from five to nine days, depending on the temperatures to which they are exposed. Eggs of the body louse attached to clothing which is not being worn may lie dormant, without hatching, for as long as thirty-five days, if exposed to cold.

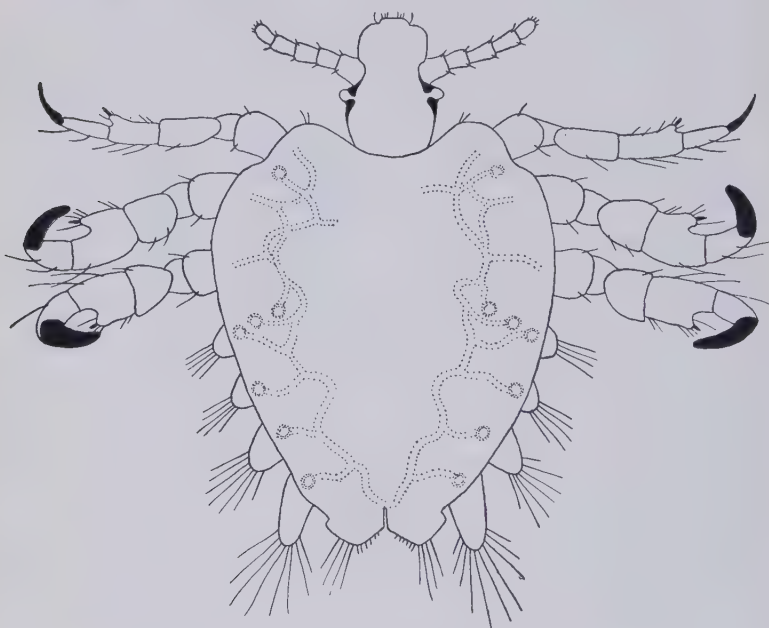


FIG. 264.—Female *Phthirus pubis*. (Original. Root)

The larval forms closely resemble the adults except for their smaller size. There are three larval stages and the adult stage is reached about twelve or fourteen days after emerging from the egg, if the larvæ are able to feed on blood regularly.

IV. *Human Lice as Disease-Carriers*

While all human lice are irritating, they are not equally important as disease carriers. The crab louse has not been incriminated as a carrier of any disease and the head louse is thought to be much less important than the body louse as a transmitter. Lice have been proved to be the vectors of typhus fever, trench fever, and the

European, North American, Indian and Algerian types of relapsing fever. It is believed that ordinarily, at least, human infections with these diseases result from rubbing crushed infected lice or their feces into a louse-bite while scratching it, rather than from injection of the causative organisms by the louse in the act of biting.

It has been shown that body lice are very delicately adapted to the normal temperature of the human body and tend to become very active and to migrate if the temperature is raised even a few degrees, so that when their host is in a febrile condition they tend to leave him. This probably explains why a parasite which is usually so intimately associated with its individual host is sometimes responsible for wide-spread epidemics of disease.

V. *Louse Control*

In ordinary civil life, louse control is a comparatively simple matter, except when one has to deal with a population with little or no idea of cleanliness and sanitation. The ordinary laundry and dry-cleaning processes are both effective in destroying lice and their much more resistant eggs or "nits" on clothing, and a bath with a kerosene or cresol soap will kill body lice on the person. Head lice may be eradicated by rubbing into the hair thoroughly a mixture of equal parts of kerosene and vinegar, covering tightly with a towel for half an hour, and then washing the hair with soap and warm water.

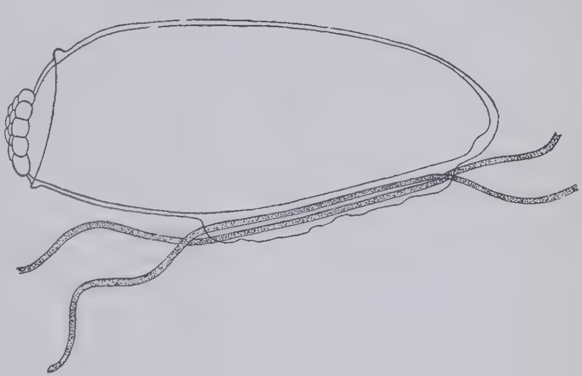


FIG. 265.—Egg of *Pediculus humanus corporis*, attached to fibers of cloth. (Original. Root)

In armies under war conditions, and in the case of immigrants and unsanitary populations who are suffering from epidemics of typhus fever, it is necessary to apply "delousing" measures to large bodies of people. This involves bathing the individuals with an insecticidal soap, together with hair-clipping or other measures when

head lice are present, and the treatment of all clothing and blankets to kill body lice and their eggs. The lice and "nits" can be destroyed by the action of heat (baking, boiling or steaming), by fumigation with hydrocyanic acid gas, or by immersing garments in gasoline, benzine, kerosene, turpentine, or the like. In actual practice, it is usual to treat most garments and bedding with steam sterilization, and to use hot-air sterilizers or cyanide gas for leather and rubber goods, furs, varnished articles and other fabrics which are injured by steam.

Conditions vary so much that it is not worth while to give any detailed account of the many different types of buildings or installations that have been devised for delousing purposes. All of them include, of course, a bath with insecticidal soap and hair-clipping, if necessary, for the individuals, together with the appropriate measures for sterilizing clothing and bedding. The two important principles to keep in mind in devising an installation to fit the conditions met with are that there should be a complete separation of the "clean" and the "infested" portions of the plant and that there should be a most meticulous inspection at the point where the individuals pass from the infested to the clean side. A "horse-shoe" arrangement, with check-rooms and sterilizers in the center, is often the most convenient plan.

When a delousing plant is not available, individuals may be protected by wearing overall suits of oiled silk or rubber, fastening tightly at wrists, neck and ankles. The use of repellant substances, such as oil of birch tar or oil of eucalyptus, and the various palliative measures, such as the use of powders, sachets, or ointments containing napthalene, iodoform, and the like, are not very satisfactory, since although these measures may kill or stupefy the lice they have no effect on the eggs.

CHAPTER L

ORDER HEMIPTERA—TRUE BUGS

Two closely related orders HEMIPTERA and HOMOPTERA share the peculiarity of having their piercing and sucking mouth parts enclosed in a *jointed* sheath formed by the labium. Within this sheath lie four slender stylets; a pair of barbed, piercing *maxillæ* and a pair of doubly-grooved *mandibles* which lock together to form a food canal and a salivary duct. The two orders differ primarily in the structure of the wings. In the HOMOPTERA both pairs of wings are membranous, while in the HEMIPTERA the basal half or two thirds of the fore-wing is thickened while the terminal half or one third remains membranous. At rest, the fore-wings form a protective covering for the membranous hind wings, the thickened basal portions of the two fore-wings lying side by side, while the membranous terminal portions overlap, one above the other, covering the tips of the hind wings. In both orders, metamorphosis is incomplete, the larvæ resembling their parents in mode of life and in structure, except for their smaller size and the absence of functional wings and sex organs.

In both orders the mouth parts seem to have been originally developed for the purpose of piercing the tissues of plants and sucking out their sap, and this is still the food taken by a great variety of forms, including many crop pests of great interest to the economic entomologist. In the HEMIPTERA, some few groups have discovered that their mouth parts are equally effective for piercing the bodies of other insects and sucking out the soft parts, and these forms have become predaceous in habit. And a few of these predaceous bugs have become parasitic in habit, finding that their beaks will also serve to pierce the skin of man and other mammals and suck blood. These few genera are the only ones of direct interest to a medical entomologist. They occur in two families, the CIMICIDÆ (bedbugs) and the REDUVIIDÆ ("assassin-bugs"). It should be noted, however, that all of the HEMIPTERA and HOMOPTERA have mouth parts of essentially the same structure as the blood-sucking forms, and that a number of them will occasionally bite human beings if carelessly handled.

I. *Family Cimicidæ—Bedbugs*

In this family the wings are vestigial, the hind wings being entirely absent while the fore-wings are reduced to little pads. Two species of the genus *Cimex* have become "habitat parasites" of man, living and breeding in houses and feeding on blood. Other species of this and related genera, closely resembling bedbugs in their general appearance, are parasitic on poultry, pigeons, swallows and bats.

The two species which are found in houses are *Cimex lectularius*

FIG. 266.—Head and thorax of *Cimex lectularius* (left) and of *Cimex hemipterus* (right). (Original. Root)

Linn. (the bedbug) and *Cimex hemipterus* Fabr. (the Oriental bedbug). The main difference between them is in the form of the prothorax (compare Figure 266), which, in *C. lectularius* is deeply sinuate anteriorly, with the middle of the dorsum convex and the sides flattened, while in *C. hemipterus* the convexity of the dorsum extends to the margins and the anterior edge is less deeply excavated. *Cimex lectularius* is found all over the world, although it is largely replaced by *C. hemipterus* in the Old World tropics. In the American tropics the latter species seems to be comparatively rare.

1. ADULT ANATOMY

The body of the bedbug is decidedly flattened dorsoventrally, as in the lice. The head bears laterally the compound eyes and the slender, four-jointed antennae. The mouth parts, forming the proboscis are attached to the anterior end of the head, but when at rest are folded back against the ventral surface of the head and prothorax. The proboscis-sheath (labium) is four-jointed.

In the thorax, the prothorax is large and conspicuous, with its anterior border more or less concave. The mesothorax is smaller, visible dorsally as the triangular mesonotum, to which are attached the pair of pad-like fore-wings or elytra. The metanotum is somewhat larger, but is largely concealed by the overlying elytra. Each of the thoracic segments bears a pair of well-developed legs with only three tarsal joints.

The abdomen is broad and rounded, particularly in the female. It consists of eight obvious segments and two more genitalic segments. At the tip of the male abdomen the asymmetrical penis sheath, projecting to the left, is very conspicuous. In the female, the genital orifice, at the tip of the abdomen is said to be used only for oviposition. In copulation, the penis of the male is said to be inserted into the copulatory pouch or organ of Berlese, whose location is indicated by a triangular incision in the posterior margin of the fourth abdominal sternite, to the right of the median line. The whole body is clothed with short stout hairs, which are often frayed out or slightly branched at their tips, particularly on the pronotum and the elytra.

2. LIFE HISTORY

The female lays a considerable number (150 or more) of white, oval eggs in several batches. The eggs hatch in about ten days or more, depending on the temperature. The five larval stages resemble the adults closely in form, but are smaller and paler in color. Each larval stage requires at least one blood-meal in order to moult and pass on to the next stage, and the female needs a blood-meal before she can develop her eggs. Bedbugs are able to live for several months, perhaps even a year, without feeding, and feed readily on rats and other animals if human beings are not available.

3. BEDBUGS AND DISEASE

Bedbugs have not been definitely incriminated as important vectors of any disease. It was long believed that the Oriental bedbug

(*Cimex hemipterus*) was the probable carrier of kala azar (see page 542) and this idea has not yet been absolutely disproved. In laboratory experiments bedbugs have been shown to be capable of transmitting relapsing fever, bubonic plague and tularæmia, but it is not probable that they are of any great importance in any of these diseases.

4. CONTROL

Bedbugs are easily killed by most insecticides if they actually come into contact with them, but their habit of lurking in all sorts

FIG. 267.—Adult males of *Triatoma megista* (left) and *Rhodnius prolixus* (right). (After Brumpt)

of deep cracks and crevices often makes them very difficult to exterminate. Barracks and similar buildings may be fumigated with cyanide gas or sulphur or heated to about 140° Fahrenheit for six hours. Kerosene, gasoline and various cresol and phenol mixtures are effective, but must be applied to beds, floors and walls with a small brush, a feather or a spray syringe to be sure of getting the insecticide into the crevices where the bedbugs hide.

II. *Family Reduviidæ—"Assassin-Bugs"*

The bugs of this family have long narrow heads, bearing prominent compound eyes, long, four-jointed antennæ and usually two

small ocelli. The proboscis is three-segmented, folded back under the head when at rest, and is usually long, slender and straight in blood-sucking genera; shorter, stouter and arched or bent in genera that feed on other insects. The prothorax is well-developed, functional wings are present and the legs are long, with three-jointed tarsi.

Most Reduviids feed on other insects, piercing their chitinous integument and sucking out the internal soft parts. Many of these

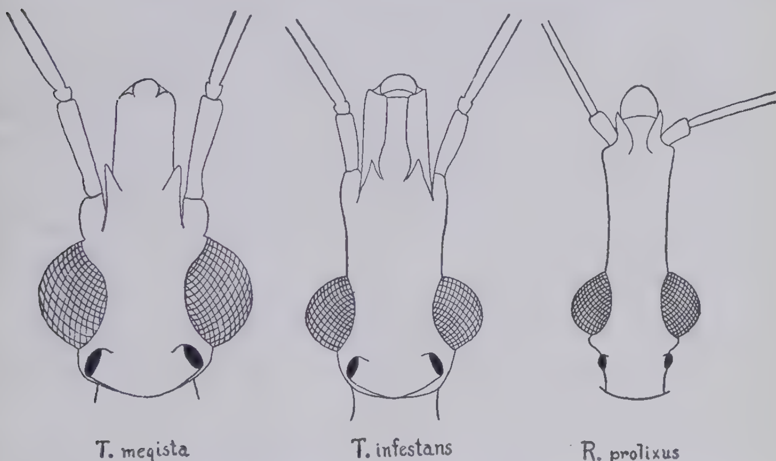


FIG. 268.—Heads of *Triatoma megista* and *infestans* and of *Rhodnius prolixus*, showing where the antennæ arise. (Original. Root)

species will occasionally bite man if carelessly handled. But in certain genera (*Triatoma* and *Rhodnius*) all the species whose habits have been studied live as habitat parasites in houses or in the nests of animals. These genera (Figure 267) are of medical interest because they include the vectors of South American trypanosomiasis, caused by *Schizotrypanum cruzi*.

I. GENERA TRIATOMA AND RHODNIUS

These blood-sucking bugs are often called cone-nosed bugs because of the great extension of the head in front of the eyes. In Brazil they are known as "barbeiros" (barbers) because they frequently bite the faces of sleepers. In Spanish America they are often called "vinchucas" or "chinchas voladoras" (flying bedbugs). The species are mostly either brownish without any striking markings,

or else dark, almost black, with regularly arranged red or yellow markings on prothorax, wings or the borders of the abdomen. A number of species frequent houses, especially the rude dirt huts of the poorer natives, and feed on human blood. Others are sometimes found in houses, but occur more often in chicken-houses or in the burrows of armadillos and rodents, and a few species have only been taken in this last habitat. It seems probable that all the species are able to transmit *Schizotrypanum cruzi,* for laboratory experiments with many different species of *Triatoma* and *Rhodnius* and one species of the related genus *Eratyrus* have been successful. The species which are of most importance in transmitting the disease to man are probably *T. megista* Burm. and *T. sordida* Stal. in Brazil, *T. infestans* Klug in Argentina and Paraguay, *T. dimidiata* Latr. in Central America and *Rh. prolixus* Stal. in Venezuela. The most widely distributed species of the whole group, *Triatoma rubrofasciata* DeGeer, which is found in North and South America, Asia and Africa, has been suggested as a possible vector of kala azar in India.

The three genera mentioned above may be distinguished by the characters given in the following synopsis (compare Figure 268):

SYNOPSIS OF THE GENERA OF BLOOD-SUCKING REDUVIIDÆ

Ocelli present; anterior coxæ short; thorax constricted anteriorly; apex of scutellum with one spine or none; ocelli behind and as far apart as compound eyes; antennæ inserted laterally..........
- Mesonotum with lateral spines .... *Eratyrus.*
- Mesonotum without lateral spines ....
  - Abdomen very broad, extending far beyond folded wings on the sides .... *Meccus.*
  - Abdomen more slender, most of it concealed by the wings when they are folded ....
    - Antennæ inserted near the anterior end of the head .... *Rhodnius.*
    - Antennæ inserted near compound eyes or else about midway between compound eyes and anterior end of head .... *Triatoma.*

CHAPTER LI

THE CLASS ARACHNIDA AND THE ORDER ACARINA

The class ARACHNIDA includes the spiders, scorpions, ticks, mites and other related groups. Although they are Arthropods they are not, strictly speaking, insects (Class INSECTA), but are included in the subject-matter of Medical Entomology because they are related to the true insects and because certain ticks and mites (Order ACARINA) cause and transmit diseases of man and domestic animals in the same way that the true insects do.

The main structural characteristics which differentiate the class ARACHNIDA from the class INSECTA are the absence of wings and antennæ, the presence of four pairs of legs, and the fact that the head and thorax are always fused together, forming a *cephalothorax*. In the order ACARINA, in which we are particularly interested, this fusion has advanced even farther, and usually head, thorax and abdomen are all fused together so that the whole body is a single, unsegmented sack.

The class ARACHNIDA is divided into about eleven orders. Of these, five include the true spiders (Order ARANEIDA) and other creatures of similar appearance, with small, compact bodies and long legs. Three other orders include the scorpions and their allies, with large bodies, short, stout legs, and a slender, elongate abdomen, which bears a sting at its tip in the true scorpions (Order SCORPIONIDEA). The other three orders are the king or horseshoe crabs, the "water-bears," and the ticks and mites (Order ACARINA). Only the last-named order is of great medical interest, although some spiders by their bites, and scorpions, by their stings, are occasionally troublesome to man. The scorpions found in the United States are too small to be dangerous, and the only spider found in this country whose bite is really serious is the black, red-spotted species sometimes called the "Black Witch" (*Latrodectes mactans*).

The Order ACARINA includes the ticks and mites, most of which are of small size. In this order the head, thorax and abdomen are all fused together forming an unsegmented body. At the anterior end of this body, a small part of the head region is usually segmented off

and hinged to the body proper to serve as a movable base for the mouth parts. This base, together with the mouth parts, bears the name of *capitulum,* and the base itself is termed the *basis capituli.* The mouth parts of the ACARINA include a pair of *chelicerœ* or *mandibles,* which sometimes bear chitinized teeth or claws at their tips; a pair of palp-like structures, the *pedipalps,* consisting of five joints or less; and a median *hypostome,* which can sometimes be seen to consist of two fused halves. This hypostome is a prominent structure covered with small backwardly-pointing teeth in the ticks, but is usually inconspicuous and unarmed in the other mites. One or more pairs of simple eyes or *ocelli* may be present, but are always placed on the anterior part of the body, never on the capitulum.

In some mites the chitinous integument is membranous throughout, in others some portions of the integument are thickened into protective plates or shields. Often there is a dorsal shield or *scutum,* covering either the entire back or the anterior portion of it. Sometimes ventral plates are present also, often around or near the anal and genital apertures. The *anus* is placed ventrally, near the posterior end of the body, in most forms. The *genital aperture* is also ventral and always anterior to the anus, sometimes so far forward that it is near the capitulum. The body and legs of mites usually bear regularly arranged hairs or bristles.

The legs are usually attached to the ventral surface of the body, the basal joints or *coxœ* sometimes resembling additional ventral plates. Usually each leg consists of about six similar joints, which are called *coxa, trochanter, femur, patella, tibia* and *tarsus.* The last joint or tarsus may bear *claws,* a pad or *pulvillus,* a *sucker* or merely some long *bristles.* In some mites the two posterior pairs of legs arise much posterior to the two anterior pairs.

Some mites have no obvious *spiracles* or respiratory apertures. In others there are spiracles on the cephalothoracic portion of the body. In the ticks and some related forms, there are a pair of *spiracles* or *stigmal plates* laterally near the coxæ of the third or fourth pair of legs.

In their life histories, Acarina usually pass through four stages, egg, larva, nymph and adult. The larva has only three pairs of legs (see Figure 269). When it moults to become a nymph it acquires a fourth pair of legs but still lacks a genital aperture. The nymph, in turn, moults and becomes an adult, with four pairs of legs and a genital aperture. Where there are sexual differences between male and female adults, as in the hard ticks, the nymphs all resemble the females in these respects.

Mites are extremely numerous both in species and in individuals and are found in all sorts of habitats. Some are ectoparasitic, others endoparasitic on or in all sorts of animals and plants. Some are terrestrial, others live in fresh or salt water. Some feed on decaying animal or vegetable matter, others on stored foods, others on plants, others on minute animals, and the parasitic forms on blood. The

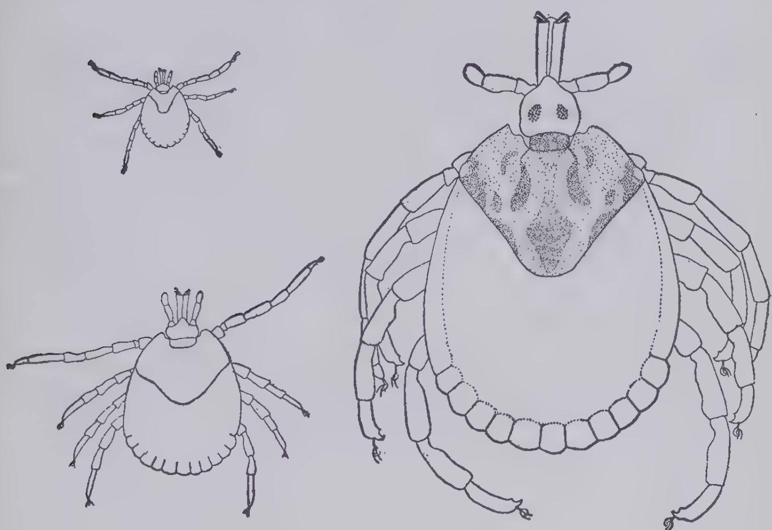


FIG. 269.—Unfed larva, nymph and adult female of *Amblyomma cajennense*, drawn to the same scale. (Original. Root)

following keys to the superfamilies and families of mites are adapted from those given by Banks (1915) and have been somewhat condensed.

KEYS TO THE FAMILIES AND SUPERFAMILIES OF THE ACARINA

I. Key to the Superfamilies of the ACARINA

1. Abdomen annulated, prolonged behind......*Demodecoidea*..Key II.
   Abdomen not annulated nor prolonged 2
2. With a distinct spiracle or stigmal plate laterally near the coxæ of the third or fourth pair of legs 3
   Without a distinct spiracle or stigmal plate in this region........ 4
3. Hypostome large, with numerous backwardly-pointing teeth .... *Ixodoidea*..Key III.
   Hypostome small, without teeth.............*Parasitoidea*..Key IV.

4. With a specialized seta arising from a pore near each posterior corner of the cephalothorax .... (*Oribatoidea*).
   Without such a specialized seta 5
5. Aquatic mites, living in water .... (*Hydrachnoidea*).
   Terrestrial or parasitic mites, not living in water 6
6. Pedipalps small, three-jointed; tarsi often with suckers; internal rod-like epimera usually present at bases of legs .... *Sarcoptoidea*..Key V.
   Pedipalps usually four- or five-jointed; tarsi never with suckers; rod-like epimera almost never present 7
7. Last joint of pedipalps in the form of a thumb-like process arising near base of preceding joint and apposable to its claw; body usually very hairy .... *Trombidioidea*..Key VI.
   Pedipalps without any thumb-like process; body usually with but few hairs .... (*Eupodoidea*)

II. Key to the Families of the DEMODECOIDEA

1. With four pairs of three-jointed legs; parasitic in the skin of mammals .... *Demodecidæ*.
   With two pairs of five-jointed legs; parasitic on plants, often in galls .... (*Eriophyidæ*).

III. Key to the Families of the IXODOIDEA

1. Scutum absent; capitulum ventral; tarsus without a pulvillus in adult; spiracle above and behind third coxa........ *Argasidæ*.
   Scutum present; capitulum anterior; tarsus with a pulvillus in adult; spiracle above and behind fourth coxa........ *Ixodidæ*.

IV. Key to the Families of the PARASITOIDEA

1. Last joint of pedipalp enlarged; spiracle above the third coxa .... (*Holothyridæ*).
   Last joint of pedipalp not enlarged; spiracle behind third coxa... 2
2. Genital aperture near the anus............. (*Spelæorhynchidæ*).
   Genital aperture at about the level of the fourth pair of coxæ .... *Parasitidæ*.

V. Key to the Families of the SARCOPTOIDEA

1. Tracheæ present; female with a short club-like hair between first and second pairs of legs .... *Tarsonemidæ*.
   Tracheæ absent; female without club-like hair in this position .. 2
2. Integument without fine parallel striations; not parasitic on birds and mammals 3
   Integument with fine parallel striations; parasitic on birds or mammals 4
3. Legs short, without a club-like hair on tarsi of first and second pairs of legs .... (*Canestrinidæ*).
   Legs longer, with a club-like hair on tarsi of first and second pairs of legs .... *Tyroglyphidæ*.

4. With a specialized hair-clasping apparatus....... *Listrophoridæ.*
   Without any special adaptations for clinging to hairs 5
5. Living on feathers of birds .... *Analgesidæ.*
   Living on or in living tissues of birds or mammals 6
6. Genital aperture longitudinal; living in skin and tissues of birds .... *Cytoleichidæ.*
   Genital aperture transverse; living in skin of mammals and birds .... *Sarcoptidæ.*

VI. Key to the Families of the TROMBIDIOIDEA

1. First and second pairs of legs with spinose processes; chitinous shields present .... (*Cæculidæ*).
   First and second pairs of legs without spinose processes; shields usually absent 2
2. Cheliceræ with claws (chelate) 3
   Cheliceræ needle-like (stylate), without claws 4
3. Tarsus of first pair of legs usually enlarged; cephalothoracic region usually with a mid-dorsal grooved organ (crista metopica) .... *Trombidiidæ.*
   Tarsus of first pair of legs not enlarged; no crista metopica present .... (*Anystidæ*).
4. Tarsi enlarged .... (*Erythracidæ*).
   Tarsi not enlarged 5
5. All legs with claws; pedipalps not enlarged; feeding on plants .... (*Tetranychidæ*).
   Claws often absent from one or more pairs of legs; pedipalps often enlarged at base and forming a forceps; predaceous or parasitic in habit .... *Chyletidæ.*

CHAPTER LII

THE TICKS (SUPERFAMILY IXODOIDEA)

The ticks are distinguished from the other mites by their toothed or armed hypostome and by the presence of a pair of definite spiracles placed just behind the third or fourth pair of coxæ. They are also decidedly larger than most mites, the newly hatched larvæ of the ticks being about the same size as the adult stage of the larger species of mites. Ticks are usually regarded as bloodsucking ectoparasites of vertebrates, although it is worth pointing out that many of them do not remain on the host after engorgement is completed and are, strictly speaking, free-living organisms during the periods when they moult and lay eggs. Most ticks are normally parasitic on certain mammals, birds, reptiles or amphibians, but nearly all species will bite man if they

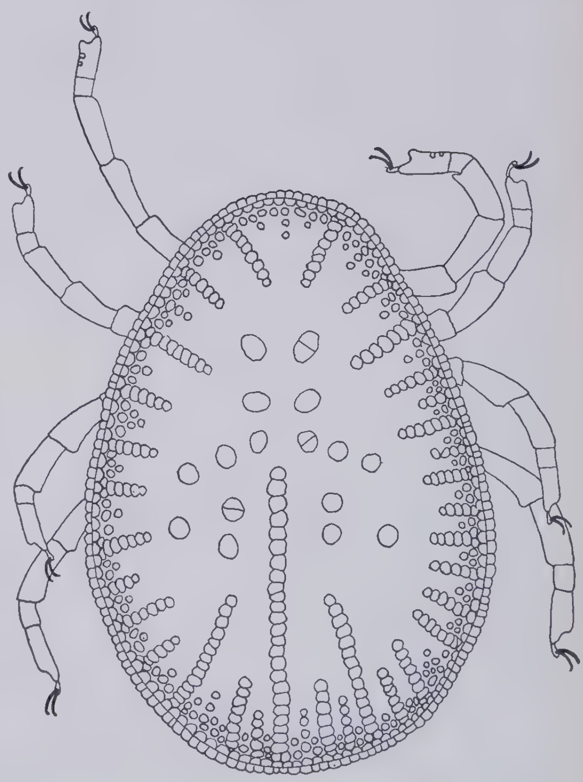


FIG. 270.—Dorsal view of a soft tick, *Argas persicus*. (Original. Root)

have the opportunity and certain species are known to be the usual carriers of human diseases. Other ticks are vectors of important diseases of domestic birds and mammals.

The superfamily IXODOIDEA is divided into two families, the ARGASIDÆ and IXODIDÆ.

In the soft ticks, constituting the family ARGASIDÆ, the two sexes are much alike (Figure 270). Neither sex has a hard dorsal scutum, the capitulum is ventrally located, the spiracles are behind the third pair of coxæ, the coxæ are not spurred and the tarsi bear no pads or pulvilli. The ticks of this family have much the same habits as

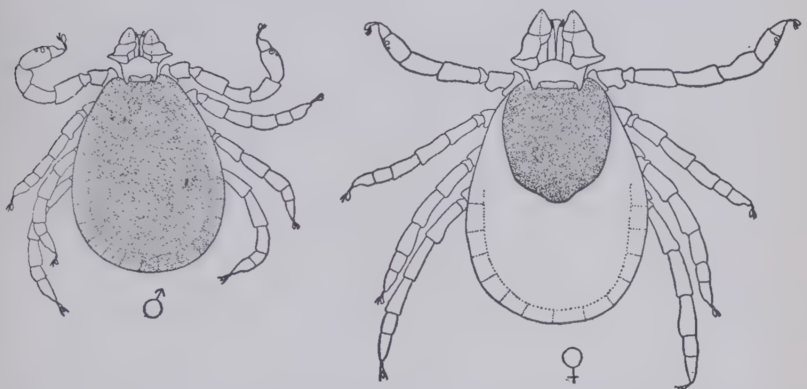


FIG. 271.—Dorsal views of male and female hard ticks, *Hæmaphysalis leporis-palustris.* (Original. Root)

bedbugs, hiding in cracks or crevices in houses or in the nests of their hosts and coming out at night to feed on the blood of the host for a short period, usually less than half an hour. The larvæ and nymphs usually feed several times before moulting and the adult female usually feeds a number of times, laying a small batch of eggs after each feed.

In the hard ticks (family IXODIDÆ) the two sexes are often very dissimilar in appearance (Figure 271), because the hard dorsal scutum, which both sexes possess, covers the entire dorsal surface in the male but extends over only a small part of the anterior portion of the dorsum of the female. The capitulum is placed at the anterior end of the body, the spiracles are behind the fourth pair of coxæ, the coxæ are generally armed with spurs and the tarsi always have pads or pulvilli as well as claws. The ticks of this family attach

themselves firmly to their hosts and remain upon them, sucking blood for days or even weeks. The larvæ and nymphs take only one blood meal in each stage and the adult female takes only a single enormous blood meal before dropping off the host to digest the blood and lay a single large batch of eggs.

I. *Family Argasidæ—Soft Ticks*

This family includes only two genera, *Argas* and *Ornithodorus*. The typical species of the two genera are distinct enough, but there are some intergrading forms which are difficult to place. The principal characteristics of the two genera are as follows:

Argas: Body thin and flat, with a sharp-edged lateral margin which is distinct even when the tick has fed; integument minutely wrinkled, with many oval or rounded discs, arranged in radiating lines.

Ornithodorus: Body thicker, with the margin thick, rounded and poorly defined, even in unfed ticks; integument covered with rounded protuberances or mammillæ, and usually without discs.

1. SOFT TICKS OF IMPORTANCE IN MEDICAL ENTOMOLOGY

Argas persicus Oken: this species is common in many parts of the tropics and subtropics. It is ordinarily parasitic on fowls, but will occasionally bite man. It is the vector of fowl spirochætosis (*Spironema gallinarum*). In Europe there are other species of *Argas* which parasitize pigeons and bats.

Ornithodorus moubata Murray: the fever tick of tropical Africa. This species has adopted exactly the mode of life of a bedbug. It lives in cracks of walls or floors of the native huts, coming out at night to feed. The life history is unusual in that the larval stage is passed in the egg, without a blood meal, a nymph emerging from the egg about twenty days after the egg was laid. This species is the vector of the tropical African type of relapsing fever (often called tick fever) caused by *Borrelia duttoni*. As is often true in tick-borne diseases, a female *O. moubata* infected with the relapsing fever spirochæte normally produces infected offspring, also capable of transmitting the disease. In the laboratory the infection has thus been passed on by a single infected female to three generations of her progeny (Möllers, 1907) without any further contact with the spirochætes. Another similar and closely related species, *Ornithodorus*

savignyi Audouin, transmits relapsing fever (*Borrelia persica*) in Abyssinia, Persia and India.

Ornithodorus talaje Guerin-Meneville; *Ornithodorus turicata* Duges: these two species are the vectors of the relapsing fever of tropical America (*Borrelia novyi*). They are sometimes found in large numbers in crude bunks or bedsteads made of bamboo and other materials which afford them numerous crevices to hide in.

Ornithodorus megnini Duges: this species rarely attacks man, but is worth mentioning because of its aberrant life history. The larvæ and nymphs are usually found in the ears of cattle and horses and are known as "spinose ear-ticks." When the nymph is full-grown it drops to the ground and moults to become an adult. The adults do not attempt to find a host, but climb up fence-posts and walls and hide in the crevices, where copulation and egg-laying occur.

The American species of Argasid ticks may be identified by the following key.

KEY TO THE AMERICAN SPECIES OF THE FAMILY ARGASIDÆ

1. Margin of body flattened, sharp-edged .... *Argas* 2
   Margin of body thick, rounded, not clearly defined .... *Ornithodorus* 3
2. Margin of body with quadrangular "cells" .... *A. persicus.*
   Margin of body striate; body narrowed anteriorly .... *A. reflexus* var. *magnus.*
3. Integument pitted .... *O. megnini.*
   Integument mammillated or granular 4
4. Fourth tarsus smooth above, without spurs or humps 5
   Fourth tarsus with a prominent subapical spur or hump dorsally. 6
5. First tarsus without humps dorsally; a lateral flap on each side of capitulum .... *O. talaje.*
   First tarsus with about three dorsal humps; no lateral flaps near capitulum .... *O. turicata.*
6. Eyes present; first tarsus with medial and subapical spurs .... *O. coriaceus.*
   Eyes absent 7
7. First tarsus with three humps and a subapical spur . . *O. furcosus.*
   First tarsus without humps but with basal and subapical spurs .... *O. rostratus.*

II. *Family Ixodidæ—Hard Ticks*

This family includes a number of genera and a very large number of species. The relatively small and inconspicuous males can be readily assigned to genera, since in many genera they have characteristically located thickened plates or shields on the ventral sur-

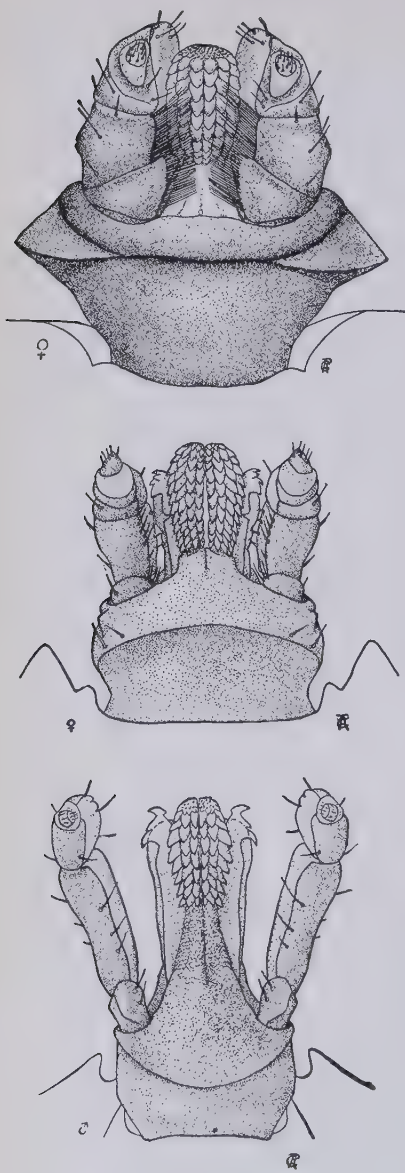


FIG. 272.—Ventral views of capitula of *Rhipicephalus* (above), *Dermacentor* (middle) and *Amblyomma* (below). (After Hunter and Hooker)

face. The females lack these ventral shields and are often difficult to identify, particularly when fully engorged. The following brief summary of the characters used in identifying the genera of the IXODIDÆ will enable the student to use the key to the genera more readily.

Capitulum (Figure 272). The *basis capituli* may appear rounded, rectangular or hexagonal in dorsal view. The mouth parts, consisting of hypostome, cheliceræ and pedipalps, may be either short (about the same length as the basis capituli) or long (much longer than the basis capituli). In the pedipalps, the elongation, when present, affects especially the second joint. The pedipalps consist of four joints, the first and third being always short, while the fourth is always reduced to a small spherical structure, usually placed in a depression near the tip of the third joint. In most genera the pedipalps ensheath the other mouth parts and the entire mouth part complex is narrower than the basis capituli, but in *Hæmaphysalis* the second joints of the pedipalps are laterally produced so that they extend beyond the edges of the basis capituli.

Body. Dorsally there is a shield or *scutum* which is comparatively small in the female but covers the entire dorsal surface in the male. When *eyes* are

present, they are placed on or near the lateral margins of the scutum. In some ticks the scutum is *ornate,* that is, it has a more or less brilliant, enamel-like coloration, often white, yellow, or red, which makes it stand out clearly in the female against the dark or brownish body-color. Around the posterior edge of the body there is sometimes a

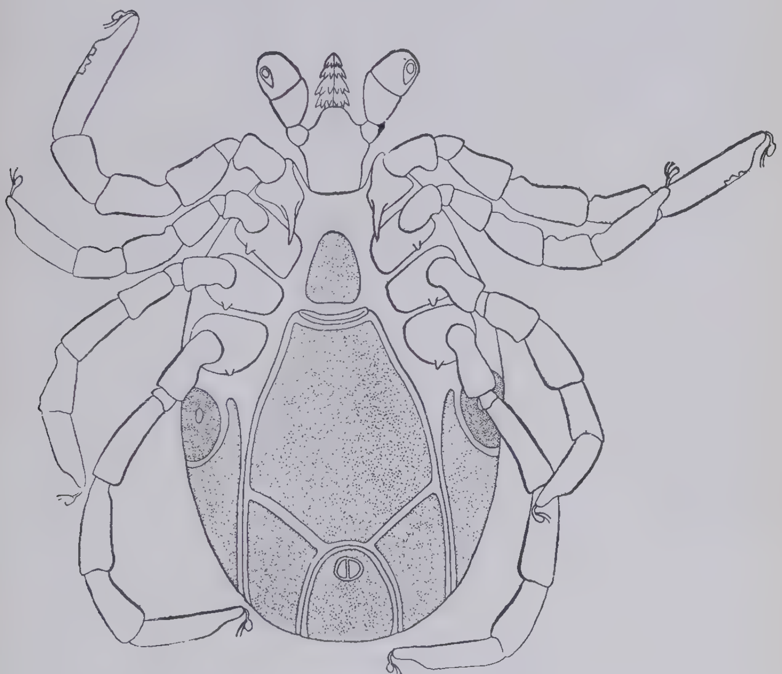


FIG. 273.—Ventral view of male *Ixodes ricinus.* (Original. Root)

submarginal furrow or groove, connected with the margin by a number of shorter grooves, which break up the margin into little rectangular areas called *festoons.*

Ventrally all adult Ixodid ticks have the *genital opening* a little behind the capitulum and the *anus* posteriorly, near the tip of the body. The four pairs of *coxæ* form shield-like plates on the ventral surface. In most of these ticks, certain grooves are readily seen ventrally. The pair of *genital grooves* begin anteriorly at the sides of the genital opening and run posteriorly and then somewhat outwardly to the posterior margin of the body. The single *anal groove*

usually connects the two genital grooves, being arched posteriorly so that it runs behind the anus, but in *Ixodes* the anal groove runs in front of the anus and both ends usually reach the posterior margin of the body, without having any connection with the genital grooves. In species having the anal groove posterior to the anus there is sometimes a *post-anal groove,* running from the middle of the anal groove toward the posterior margin.

In the males of certain Ixodid genera, *ventral plates* are present. In *Rhipicephalus, Hyalomma* and *Boophilus* (Figure 275) there are a pair of *adanal* plates on either side of the anus and a pair of *accessory plates* lateral to the *adanal plates* and separated from them by the genital grooves. In *Margaropus* there is a posteriorly forked *preanal plate,* which may correspond to fused adanal plates. In the male of *Ixodes* (Figure 273), the greater part of the ventral surface is covered with plates, consisting of a pair of *adanal plates,* a pair of *epimeral plates* outside the genital grooves, an *anal plate* which bears the anus, a large *median plate* between the anus and the genital opening, and a small *pregenital plate* between the genital opening and the capitulum.

Behind and above the fourth pair of coxæ are the *spiracles,* which are sometimes round or oval but often more or less comma-shaped. As has been pointed out by Stiles (1910) the shape and minute structure of the spiracles are often useful in differentiating closely-related species of ticks.

KEY TO THE GENERA OF THE FAMILY IXODIDÆ

1. Anal groove running in front of anus; pedipals usually spatulate in form; male with numerous ventral plates .... *Ixodes.*
   Anal groove either running behind anus or so indistinct that it cannot be seen clearly 2
2. Mouth parts about as long as basis capituli; second joint of pedipalps not much longer than wide 3
   Mouth parts much longer than basis capituli; second joint of pedipalps much longer than wide 8
3. Anal groove plainly visible; festoons usually present 4
   Anal groove absent or indistinct; festoons absent 7
4. Second joint of pedipalps laterally produced, so that it extends beyond the edges of the basis capituli; eyes absent .... *Hæmaphysalis.*
   Second joint of pedipalps not laterally produced; eyes present. 5
5. Basis capituli rectangular in dorsal view; scutum usually ornate; male without ventral plates; fourth coxa of male much larger than the others .... *Dermacentor.*
   Basis capituli hexagonal in dorsal view; scutum usually not ornate 6

6. Male without ventral plates and with fourth coxa much larger than the others .... *Rhipicentor.*
   Male with ventral plates and with fourth coxa not much larger than the others .... *Rhipicephalus.*
7. Male with forked pre-anal plate; joints of fourth pair of legs greatly swollen .... *Margaropus.*
   Male with paired adanal and accessory plates; joints of fourth pair of legs normal .... *Boophilus.*
8. Eyes absent; males without ventral plates........... *Aponomma.*
   Eyes present 9
9. Eyes submarginal; males with ventral plates........ *Hyalomma.*
   Eyes marginal; males without ventral plates ...... *Amblyomma.*

I. LIFE HISTORY OF IXODID TICKS

The majority of Ixodid ticks whose life history is known have what is called the "three-host" type of life-cycle. In such a tick as

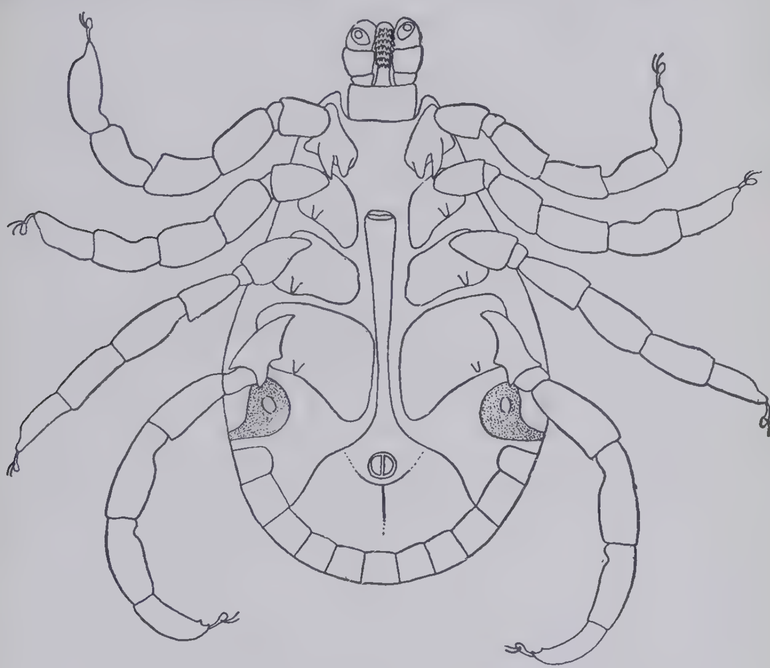


FIG. 274.—Ventral view of male *Dermacentor andersoni.* (Original. Root)

Dermacentor andersoni, the spotted fever tick, for example, the larval tick after hatching from the egg climbs to a blade of grass

or a bush and waits for a host to come within its reach. When it gets on a host it attaches itself, engorges with blood and drops off again, digesting the blood-meal and moulting to become a nymph on the ground. The nymph repeats this procedure on a second host and

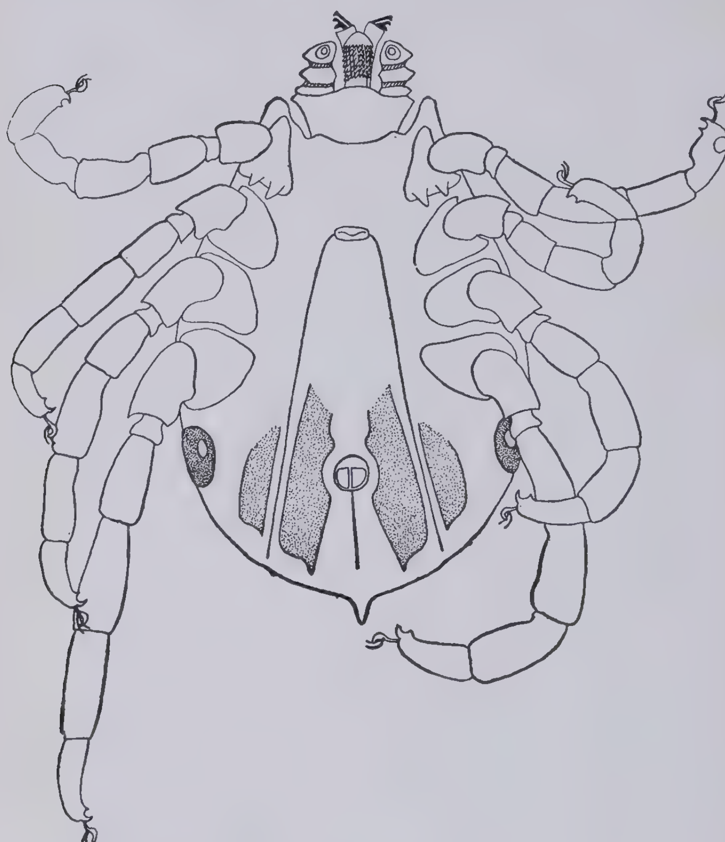


FIG. 275.—Ventral view of male *Boöphilus annulatus*. (Original. Root)

again drops off to digest its meal and transform to the adult stage. The adult female is fertilized by the male either before or after she becomes attached to a third host. When fully engorged, the female drops from the host, digests the blood-meal and lays a very large batch of eggs before dying. Not infrequently, Ixodid ticks have different species of hosts in their different stages. In the case of *Dermacentor andersoni,* for example, the larvæ and nymphs are found

in the greatest numbers on ground-squirrels and other rodents, while the adults are most numerous on cattle, horses and other large mammals.

It is obvious that this "three-host" type of life-cycle is a rather wasteful one, since each tick has to be lucky enough to have a host come within its reach three separate times in order to attain the adult condition and reproduce. A few species of Ixodid ticks are known

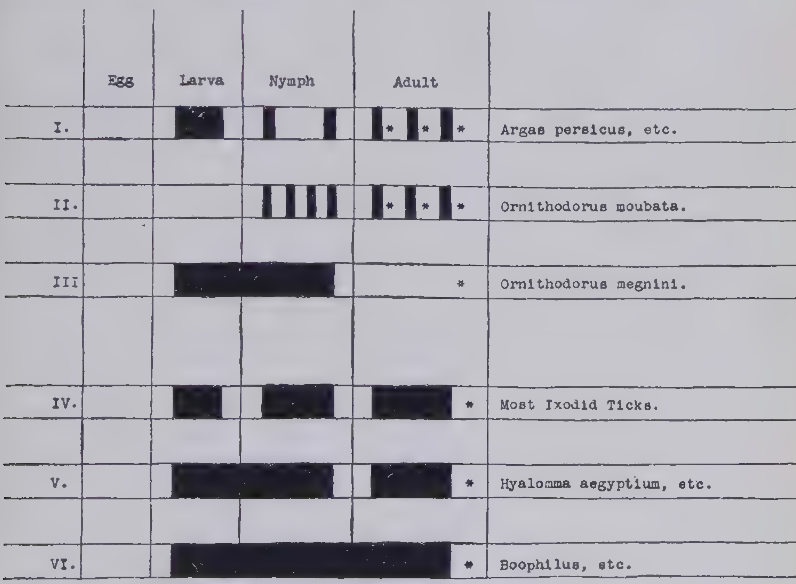


FIG. 276.—Diagram illustrating the different types of life-cycles of various ticks. (Original. Root)

which have adopted the more efficient plan of remaining on a single host individual during two or even during all three stages of their life-cycle. In three species (*Rhipicephalus evertsi* and *bursa* and *Hyalomma ægyptium*) the larval and nymphal stages remain on the same individual host. In the common cattle-ticks of the genus *Boophilus* and in certain species of *Dermacentor* (*nitens, albipictus, nigrolineatus*) the complete cycle requires only one host individual, since the larvæ which succeed in attaching themselves to a host remain on that host until they drop off as engorged adults. In ticks with this type of life-cycle, the passing on of a disease-producing organism from an infected female to her progeny, which is the rule in all tick-borne disease, is absolutely essential to the transmission of the dis-

ease in nature, since each tick feeds on only a single host individual.

The table (Figure 276) illustrates graphically the various types of life cycles found in ticks. The black rectangles in the columns headed "larva," "nymph" and "adult" indicate approximately the periods during which the ticks are attached to their host. The asterisks in the column headed "adult" show the time of oviposition by the female.

2. NOTES ON SOME OF THE GENERA OF IXODID TICKS

Ixodes Latreille: the ticks of this genus are sharply separated from the other Ixodid ticks by the position of the anal groove and the number of ventral plates present in the male. The spatulate pedipalps are also very characteristic. Two small groups of species which parasitize marine birds and bats, respectively, are separated generically from the other forms by some authors. The more typical species are mainly parasites of large and small mammals. The best-known species is *I. ricinus* (Figure 273), which is found on sheep, cattle and various wild mammals in Europe, North Africa, Asia and North America. *I. hexagonus* is found on many small mammals in Europe and *I. hexagonus* var. *cookei* has been taken from a number of small mammals in the United States. *I. holocyclus* is an Australian species which causes tick paralysis of human beings and domestic animals. Many other species are described and illustrated by Nuttall *et al.* (1911).

Hæmaphysalis Koch: the lateral projection of the second joints of the pedipalps is especially characteristic of this genus. In the United States the most abundant species is *H. leporis-palustris* of rabbits (Figure 271). *H. leachi* is a common dog tick in Africa and also occurs in Asia and Australia. *H. cinnabarina* has been frequently found on birds in the United States, but the variety *punctata* of Europe has usually been taken from the larger domestic animals. Other species are described and illustrated by Nuttall and Warburton (1915).

Dermacentor Koch: this genus includes a number of very similar species. Stiles (1910) has pointed out the value of the form and structure of the spiracles for distinguishing the species of this genus. It includes the common "wood-ticks" and "dog-ticks" of the United States, *D. variabilis* in the Eastern States, *D. andersoni* (Figure 274) in the Rocky Mountain region and *D. occidentalis* on the Pacific

coast. In Europe, Asia and Africa *D. reticulatus* is found on many of the larger mammals. *D. nitens* is found in the ears of horses in the American tropics.

Rhipicephalus Koch: this genus is connected with *Dermacentor* through the small and unimportant genus *Rhipicentor* Nuttall and Warburton, in which the male resembles *Rhipicephalus* dorsally and *Dermacentor* ventrally. *Rhipicephalus* includes a number of species, most of which are African. *R. sanguineus* is widely distributed in warm regions, including the southern United States, occurring especially on dogs. *R. bursa* is found on sheep and cattle in Africa and Southern Europe. *R. evertsi, R. appendiculatus, R. simus,* and *R. capensis* are tropical African species found on cattle and horses.

Boophilus Curtice: this genus and the closely related *Margaropus* Karsch differ from all other Ixodid ticks in lacking an anal groove. It includes the common "cattle-tick" of the southern United States, *B. annulatus* (Figure 275). Very similar species or varieties occur in other parts of the world, for example, *australis* in Australia, South America; *decoloratus* in Africa, and so forth. In all these forms the male is exceedingly small as compared with the enormous size attained by engorged females.

Hyalomma Koch: this genus includes only a few species, of which *H. ægyptium* is the most important. It is found on cattle and other large mammals in Africa, Asia and southern Europe. The male has ventral plates and also two protrusions from the tip of the abdomen which are capped with chitinous points.

Amblyomma Koch: this includes more species than any other genus of ticks. About half the species are American, the rest are distributed in Africa, Asia and Australia. Many species are parasitic on large mammals, many others on reptiles or amphibians, fewer on small mammals and very few on birds. In all the species the scutum is ornate, in some very brilliantly colored. *A. americanum* is found on cattle in the southern United States and tropical America. It is sometimes called the "lone star tick," because of the silvery spot at the tip of the female scutum. *A. maculatum* also occurs on these hosts in the same general region. *A. cajennense* (Figure 269) is very abundant in many parts of tropical and subtropical America. It is found on many of the larger mammals, including man, and the larvæ or "seed-ticks" sometimes attack human beings in large numbers, causing great annoyance. *A. hebræum,* the "bont tick" of South Africa, is found on many large mammals, both wild and domestic. *A. dissimile*

is common on snakes, lizards and toads in the American tropics. For the numerous other species see Robinson (1926). The closely related genus or subgenus *Aponomma* differs from *Amblyomma* in the more rounded body form and the absence of eyes. The species of *Aponomma* occur on reptiles, especially snakes, in the Old World tropics.

3. IXODID TICKS AND HUMAN DISEASE

The only human disease transmitted by Ixodid ticks is Rocky Mountain spotted fever, which occurs in the Rocky Mountain region of the United States, especially in Montana and Idaho. The disease is very similar to typhus fever. It is probably primarily a disease of wild rodents and is transmissible to man and laboratory animals. A *Rickettsia*-like organism, *Dermacentroxenus rickettsi,* has been described as the causative organism (Wolbach, 1919). The disease is transmitted in nature by the bites of *Dermacentor andersoni* and *Hæmaphysalis leporis-palustris.* In laboratory experiments *Dermacentor variabilis, D. marginatus* and *Amblyomma americanum* have been shown to be capable of transmitting the infection (Mayer, 1911). The ticks can become infected in either the larval, nymphal or adult stage and remain infective for the rest of their lives. The female transmits the infection to her offspring.

In nature only a very small percentage of ticks are infective and human cases are not very common except in certain restricted localities. By way of control, measures for reducing the number of ticks have been used, such as dipping domestic animals in an arsenical solution, burning over the infested areas or grazing sheep on them so that they will pick up the ticks, which soon die in their wool. Tourists, campers and hikers should be careful not to allow ticks to become attached to their bodies when they are in a region where Rocky Mountain spotted fever is known to occur.

In several different parts of the world there occurs a progressive paralysis of man or animals, apparently as a direct result of the bites of certain species of ticks. This tick paralysis may result in death if neglected, but the removal of the engorging tick is said to result in speedy recovery without any injurious sequelæ. In the Rocky Mountain region of North America, tick paralysis of children and of sheep is caused by the bites of *Dermacentor andersoni.* In Australia a similar disease of human beings and domestic animals is produced by *Ixodes holocyclus.* In Africa *Ixodes pilosus* causes a similar disease of sheep.

4. IXODID TICKS AS CARRIERS OF DISEASES OF DOMESTIC ANIMALS

The Ixodid ticks are of much greater importance in veterinary than in medical entomology, since they are the vectors of a whole group of important diseases of domestic animals, caused by protozoa of the *Piroplasma* or *Babesia* type. No protozoan of this group has yet been found in man.

In all of these diseases, the causative organism is transmitted by an infected female tick to her progeny, but there are many variations as to the stage in which the ticks become infected and the subsequent stage in which they are infective to new hosts. In the following table are listed the principal diseases of this type with their causative organisms, the animals which they usually affect, the ticks known to be vectors of the diseases and, where this has been investigated, the stage in which the tick becomes infected (inf.) and that at which it is capable of transmitting the disease (trans.). The larval, nymphal and adult stages are represented by the letters L, N and A, and A2 means the adult stage of the next generation. The table also includes two diseases or parasites of domestic animals which are transmitted by ticks but do not belong to the *Piroplasma* group of diseases.

Disease (and causative organism)	*Host*	*Tick vector*	*Inf.*	*Trans.*
Texas cattle fever (*Babesia bovis*)	Cattle	*Boophilus annulatus* and varieties	A	L
		Rhipicephalus capensis		
East Coast fever (*Babesia mutans*)	Cattle	*Boophilius annulatus* var. *decoloratus*		
Redwater (*Babesia divergens*)	Cattle	*Ixodes ricinus*		
		Hæmaphysalis cinnabarina var. *punctata*		
Biliary fever (*Babesia caballi*)	Horses	*Dermacentor reticulatus*	N	A
Biliary fever (*Nuttallia equi*)	Horses	*Rhipicephalus evertsi*	N	A
Carceag (*Babesia ovis*)	Sheep	*Rhipicephalus bursa*	A	A2
Malignant jaundice (*Babesia canis*)	Dogs	*Dermacentor reticulatus*	N or A	A2
		Hæmaphysalis leachi		
		Rhipicephalus sanguineus		
East Coast fever (*Theileria parva*)	Cattle	*Dermacentor reticulatus*	L	N
		Dermacentor nitens	N	A
		Rhipicephalus evertsi	A	L
		Rhipicephalus appendiculatus		
		Rhipicephalus simus		
		Rhipicephalus capensis		
		Hyalomma ægyptium		

Disease (and causative organism)	*Host*	*Tick vector*	*Inf.*	*Trans.*
(*Anaplasma marginale*)	Cattle	*Rhipicephalus simus*		
		Boophilus annulatus var. *decoloratus*		
(*Anaplasma argentinum*)	Cattle	*Boophilus annulatus* var. *australis*		
Heartwater (a filterable virus)	Sheep	*Ambylomma hebræum*		
(*Hæmogregarina canis*)	Dogs	*Rhipicephalus sanguineus*	N	A

CHAPTER LIII

OTHER ACARINA OF MEDICAL IMPORTANCE

Comparatively few of the ACARINA, excluding the IXODOIDEA or ticks, are of medical importance. Only in the case of Tsutsugamushi disease has a mite been incriminated as a vector of a human disease, and the number of mites which attack the human skin, causing one type or another of acarine dermatitis, is very small in comparison with the number of known species. In this chapter there will be attempted only a brief review of the groups of medical interest, taking no account of the numerous other forms.

I. *Superfamily Demodecoidea*

This superfamily includes the phytophagous mites of the family ERIOPHYIDÆ, many of which produce galls on the leaves and twigs of plants, and the family DEMODECIDÆ, which has but one genus, *Demodex*. *Demodex folliculorum* (Figure 277) is said to be parasitic in the sebaceous glands and hair follicles of a large proportion of the human race. It appears to do no particular damage to its host, whereas related species or varieties of *Demodex* cause severe mange in dogs and damage the skins of swine and cattle.

FIG. 277.—Adult *Demodex folliculorum*. (After Osborn)

II. *Superfamily Parasitoidea*

The Family PARASITIDÆ includes a considerable number of parasitic forms. Banks divides it into five subfamilies, which may be distinguished as follows:

KEY TO THE SUBFAMILIES OF THE FAMILY PARASITIDÆ

1. Spiracle and peritreme nearly or quite dorsal....*Spinturnicinæ*.
   Spiracle and peritreme ventral 2
2. No shield or chitinized area around the anus....*Halarachninæ*.
   An anal shield present 3

3. First pair of legs emerging through the same body opening as the capitulum ....(*Uropodinæ*).
   First pair of legs not emerging with the capitulum 4
4. Tips of cheliceræ without true teeth, either needle-like or harpoon-like ....*Dermanyssinæ*.
   Tips of cheliceræ toothed ....*Parasitinæ*.

The subfamily SPINTURNICINÆ includes mites parasitic on bats and various birds. Species of *Pteropus* are often found on bats, especially on the wing membranes.

The HALARACHNINÆ includes species which are found in the bronchial passages and lungs of seals and monkeys. The UROPODINÆ are often found on insects, but are probably not really parasitic upon them.

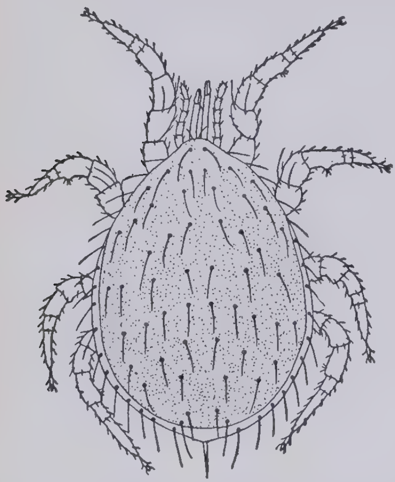


FIG. 278.—Adult of *Lælaps echidninus*. (Original. Root)

The DERMANYSSINÆ are all parasitic on birds, mammals or reptiles. This group has recently been revised by Ewing (1922). *Dermanyssus gallinæ* is a common chicken mite which sometimes attacks man, causing a dermatitis. A rat mite, *Liponyssus bacoti*, is also said to attack human beings at times.

Most of the PARASITINÆ are not parasitic on vertebrates, but this subfamily includes the genus *Lælaps*, species of which occur on small mammals and in their nests. *Lælaps echidninus* (Figure 278) is the common rat mite in most regions of the world, and is often found in very large numbers on rats and in their nests. According to Miller (1908) this mite is the vector of *Hæmogregarina muris*, a blood-parasite of rats. The species of *Lælaps* apparently do not attack man readily.

III. *Superfamily Sarcoptoidea*

I. FAMILY TARSONEMIDÆ

Many of the mites of this family are destructive to cultivated plants, and are therefore of considerable economic importance.

Others are beneficial, since they are predaceous on certain insect pests of crops. One of these species, *Pediculoides ventricosus,* is often predaceous on the larvæ of several minute insects which infest grain and straw. Threshing crews, grain-handlers and people sleeping on mattresses stuffed with unsterilized straw are sometimes attacked by large numbers of these mites, producing a severe and annoying skin eruption (see Webster, 1910).

2. FAMILY TYROGLYPHIDÆ

Many species of these "cheese mites" live and feed upon stored food products of various kinds, and some of them will attack man at times. Species of *Glyciphagus,* for example, are found in sugar and may produce a dermatitis known as "grocer's itch." Diseases known as "copra itch," "coolie itch," and the like are also produced by mites of this family. Since these mites occur in all sorts of food, they are frequently swallowed by human beings, and the mites and their eggs are often encountered when making fecal examinations to detect the presence of protozoa or the eggs of helminths.

3. FAMILY LISTROPHORIDÆ

These are the so-called "hair-clasping mites" of small mammals, which cling to the hairs and feed upon them. Although parasitic, they are of no medical importance, nor are the mites of the families CYTOLEICHIDÆ and ANALGESIDÆ, which are parasitic on fowls and other birds.

4. FAMILY SARCOPTIDÆ

This family includes the itch and mange mites of man, mammals and birds, and is of great medical and veterinary interest. Most of the species are small, with striated integument and the two anterior pairs of legs widely separated from the two posterior pairs at their origin. Some of the legs usually end in stalked suckers, others in long bristles. There are often sexual differences in this respect. The following key to the genera of SARCOPTIDÆ is adapted from Banks (1915).

KEY TO IMPORTANT GENERA OF THE FAMILY SARCOPTIDÆ

1. Anus on the dorsal surface 2
   Anus on the ventral surface 3
2. Male without suckers on the third pair of legs; parasitic on various small mammals ....*Notoedres.*

Male with suckers on third pair of legs; parasitic only on bats .... *Prosopodectes.*
3. Stalks of suckers at end of legs jointed ....*Psoroptes.*
Stalks of suckers not jointed 4
4. Females without any suckers on the legs; parasitic on birds .... *Cnemidocoptes.*
Females with suckers on first two pairs of legs, at least; parasitic on mammals 5
5. Legs very short; in the male, third and fourth pairs of legs about equal in size ....*Sarcoptes.*
Legs longer; in the male, third pair of legs much larger than fourth 6
6. Female with suckers on the fourth pair of legs......*Chorioptes.*
Female without suckers on the fourth pair of legs 7
7. Male with posterior end of body bilobed............*Caparinia.*
Male with posterior end of body not lobed..........*Otodectes.*

The genera *Sarcoptes* and *Notoedres* include the "itch mites" of man and other mammals. The species found on man is *Sarcoptes scabiei.* In these itch mites, the pregnant female burrows into the skin, laying eggs along the burrow as she progresses. An intolerable itching is produced, followed by inflammation and pustule formation. As with most forms of acarine dermatitis, sulphur ointment is the standard remedy. The skin should be repeatedly washed with soap and water before applying the ointment. Other species or varieties of *Sarcoptes* cause similar conditions known as itch or mange in various wild and domestic animals. Mites of the genus *Notœdres* produce similar diseases in cats and other small mammals.

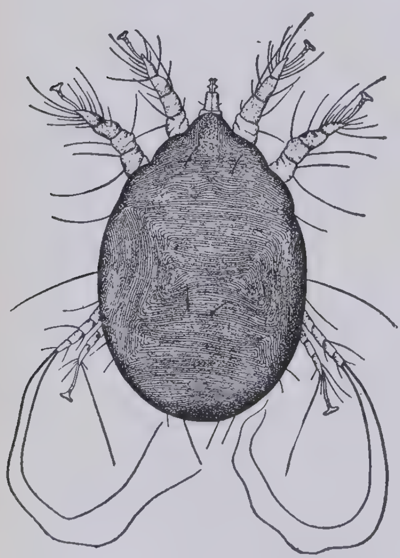


FIG. 279.—Adult female of *Psoroptes communis,* as an example of a Sarcoptid mite. (After Salmon and Stiles)

Most of the other genera of SARCOPTIDÆ may be lumped together as "scab mites." These mites do not burrow into the skin, but remain on the surface, often producing such irritation that a many-layered scab is produced. Beneath this scab and between the layers the mites may

be present in very large numbers. The species *Psoroptes communis* (Figure 279) has several varieties which cause sheep scab, Texas itch of cattle and mange in horses and dogs. *Psoroptes cuniculi* often causes extensive scab-formation in the ears of laboratory rabbits. Species of *Chorioptes* and *Otodectes* also produce similar diseases in horses, sheep and cattle. In the genus *Cnemidocoptes,* parasitic on birds, *C. mutans* causes the "scaly leg" disease of poultry while *C. gallinæ* is called the "depluming mite" of fowls because it irritates the skin so much that the hens pluck out their feathers.

IV. *Superfamily Trombidioidea*

1. FAMILY CHYLETIDÆ

Some species of this family are parasitic, though none of them are of much importance. One species, *Myobia musculi,* is frequently found on house mice. It is a very small mite, with the first pair of legs very stout and modified for grasping the hairs of its host.

2. FAMILY TROMBIDIIDÆ

This family includes, among other forms, the "harvest mites," "chiggers" or "red-bugs," which are often so annoying to human beings. These very minute, red mites which attack man in many different parts of the world, are the six-legged larval stage of mites of the genus *Trombicula.* The nymphal and adult stages of these mites, which are not parasitic but feed on arthropod excreta, decaying vegetable matter, and the like, may be easily differentiated from the other genera of the family by the decided constriction of the body (see Figure 280), which defines the limits of cephalothorax and abdomen. The nymphs and adults are very thickly clothed with feathered hairs, but the larvæ have only scattered hairs of the same type (see Figure 280).

Man is apparently only an accidental host for these larval mites. The Japanese species are found in large numbers on field mice, particularly on the ears. According to Ewing (1921, 1926) turtles and perhaps snakes are important hosts of the common American species. Ewing (1923) states that the species which occurs in the eastern and southern United States is *Trombicula tlalzahuatl* Murray, originally described from Mexico.

In Japan, the larvæ of *Trombicula akamushi* (Figure 280) have been proved to be the vectors of Tsutsugamushi disease, also called Japanese river (or flood) fever. This disease is much like typhus fever and Rocky Mountain spotted fever, and its causative agent is not yet known. It occurs in certain limited areas, near rivers, in

FIG. 280.—Larva (left), nymph (center) and adult (right) of *Trombicula akamushi*. Not, of course, to the same scale. (After Nagayo *et al.*)

Japan. The same or similar diseases, believed to be also carried by *Trombicula* larvæ, are reported from Formosa, China and Sumatra. In the last-named region the disease is known as "pseudo-typhus."

In Japanese localities where Tsutsugamushi disease has been studied, Nagayo and others (1921) have found larvæ of five species of *Trombicula* on field mice, but find that only one of these species (*T. akamushi*) attacks man.

There are a number of other genera of TROMBIDIIDÆ, but not much is known of their habits and life-histories. In some genera, the larvæ are parasitic on house-flies, grasshoppers and other insects, but apparently do not attack vertebrates.

CHAPTER LIV

NOTES ON COLLECTING AND PRESERVING INSECTS OF MEDICAL INTEREST

I. *Collecting*

The insects of medical interest may be roughly divided into three groups, the blood-sucking flies, the flies whose larvæ live in feces or carcasses or parasitize living mammals and the ectoparasitic insects and ACARINA.

The adults of the blood-sucking flies can be captured while feeding on man or on a tame horse or cow used as bait. This method will secure only the females of those groups in which this sex alone feeds on blood. Males of mosquitoes and Tabanids can be secured in numbers only by breeding out specimens from the larvæ, which has the added advantage of procuring perfect and undamaged specimens.

Similarly the adults of the muscoid flies whose larvæ live in filth or carrion or are parasitic, may usually be collected on appropriate baits or around the animals their larvæ parasitize. But in this case also, better specimens are usually obtained by breeding out adults from eggs laid by captive females or from captured larvæ.

The ectoparasitic forms are usually collected from the bodies of their hosts or in the nests of the hosts. Fleas may also be bred from the nests of animals and birds by enclosing the nest in a box or other container, with moist blotting-paper added to maintain a humid atmosphere. When fleas, lice and ticks are collected, the host species should be accurately identified and recorded.

Most of the smaller blood-sucking flies can be captured in test-tubes or in a chloroform tube, prepared by placing rubber bands or a slice of a rubber stopper in the bottom of a large tube and allowing the rubber to soak up all the chloroform it will absorb. The rubber should then be prevented from coming in contact with the insects by pushing a piece of blotting paper or a wad of cotton tied up in gauze down upon it. Such killing tubes may be used for some time without the addition of any more chloroform, if they are kept tightly corked when not in use. For capturing the larger flies, such as Tabanids and Muscoid flies, an insect net is often necessary. The

bag should be made of bobbinet or fine-meshed gauze, so that the net may be used to capture mosquitoes and black-flies occasionally.

Parasitic insects may be stupefied by chloroform and then picked from their hosts with fine forceps or combed out from the fur with a fine-toothed comb. They are usually placed directly into vials of alcohol to kill and preserve them. If captured alive, lice, mites and ticks may be killed by pouring over them water which is not quite boiling hot. This tends to make them die with legs well extended. This is also the best method of killing larvæ of the Muscoid flies. All material killed in hot water should be transferred to alcohol for preservation.

II. *Preserving*

Adult insects and ticks will keep indefinitely if they are simply allowed to become dry and then are preserved from breakage, insect pests and mold. In permanent collections, insects are usually transfixed with special insect-pins and pinned in rows into cork-lined boxes or cabinets. Large flies, like Tabanids and the Muscoid flies, may be pinned with No. 3 pins. Smaller flies, like mosquitoes, are usually impaled upon the points of very fine, short pins (called "minuten pins") which have been previously thrust through a small strip of cork or a rectangular bit of cardboard or celluloid. The other end of the cork or celluloid is then transfixed by a large insect pin (No. 5 is very convenient for this purpose) by which it may be handled and pinned into the cabinet. When traveling, it is often most convenient to preserve mosquitoes and other small flies in pill-boxes partly filled with cotton. If a number of such pill-boxes are kept in a tin can with tight-fitting cover, they can be conveniently fumigated at intervals, with a few drops of carbon disulphide, to destroy the minute insect pests which would otherwise eat the specimens. Specimens preserved in this way may later be glued to the tips of wedge-shaped bits of cardboard with a tiny drop of shellac and pinned into the insect box or cabinet with other specimens.

The larvæ and larval and pupal skins of mosquitoes and other small flies may be mounted in balsam on microscopic slides for study and permanent preservation without any special treatment. In selecting *Anopheles* larvæ for total mounts, the least pigmented and most transparent larvæ should be picked out, in order to obtain the best results. In mounting Culicine larvæ, it is often advisable to cut the larva in two at the seventh abdominal segment, mounting the anterior

portion to give a dorsal view and the posterior portion to give a lateral view.

In making balsam mounts of larger fly larvæ and of small adult flies, fleas, lice and ticks the usual method is to soak the insects in 10 per cent solution of sodium or potassium hydroxide until the soft parts are destroyed, leaving only the chitinous integument. This method is also used in preparing the male hypopygia of mosquitoes, and the like, for mounting. The process should be carefully watched, the object being to destroy the internal structures as completely as is possible without bleaching or damaging the external chitinous parts. The process can be speeded up by warming the liquid and even boiling temperatures are sometimes used, but the cold process, while much slower, usually yields better preparations. After treatment with caustic soda or potash, the insects must be thoroughly washed in water before putting them into alcohol.

Before insects and their larvæ and larval skins, either treated with caustic potash or not, can be mounted in Canada balsam under the cover-glass, they must be dehydrated and cleared. This is most easily accomplished by soaking them for some minutes, first in 95 per cent ethyl alcohol and then in carbol-xylol (carbolic acid crystals—1 part and xylol—3 parts). In the tropics, especially, carbol-xylol is essential, on account of the extreme difficulty of keeping absolute alcohol water-free in a humid atmosphere. Sometimes weak-skinned larvæ tend to collapse when passed directly from carbol-xylol into balsam. This may be avoided by passing them from carbol-xylol into cedar oil (the kind prepared for use as a clearing agent, not the thickened cedar oil used with oil-immersion lenses) and then into balsam. Cedar oil also has the useful property of absorbing small air-bubbles which sometimes get inside the specimens and are difficult to remove in any other way.

Some authorities prefer to stain caustic potash preparations before mounting them, particularly lice and the male hypopygia of small flies. Acid Fuchsin or Magenta Red are used, after the caustic potash treatment and thorough washing, but before the preparations are placed in alcohol.

It is impossible to overemphasize the importance of careful labeling of all specimens collected. The label should include place and date of collection and, in the case of parasitic forms, the name of the host. The name of the specimen and of the collector are usually added, also. Pinned insects should bear a small paper label on the pin. Specimens preserved in alcohol should have a paper label,

written in waterproof India ink, inside the vial, with the specimens. Pill-boxes may be labeled, of course, by writing on the cover. Specimens mounted on slides may have labels pasted on at one or both ends of the slide.

Slide mounts will, of course, be studied under the compound microscope by transmitted light. For studying mosquitoes and other small flies, also unmounted fleas, lice and ticks, a binocular microscope is almost indispensable, although much may be accomplished with a dissecting microscope or a good hand-lens.

BIBLIOGRAPHY

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The literature of Parasitology is contained principally in textbooks and reference books on the subject, textbooks and reference books on tropical medicine, and in journals of parasitology, tropical medicine, zoölogy and general biology. The authors list below what they believe to be the more important of the comprehensive books and monographs and also a list of the journals that include, from time to time, papers on parasitology. Titles are abbreviated in a few cases to save space, and the names of journals are in almost all cases abbreviated according to the system now prevalent among scientific writers. The method used is to give the name of the author followed by the date of publication, then the title of the paper, the journal in which it appeared, the volume of that journal and finally the first and last pages of the paper separated from the volume number by a colon.

I. Protozoölogy

1. BOOKS AND JOURNALS

a. Books on Protozoölogy (In whole or in part)

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II. HELMINTHOLOGY

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